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Urban-Small Building Complex Environment: W07US Stability Analysis and Inter-Study Comparison, Volume AS-2

by Gail Vaucher

ARL-TR-4452   **May 2008**

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White Sands Missile Range, NM 88002-5501

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14. ABSTRACT

Urban atmospheric stability patterns impact military and civilian health, tools, operations, and planning. By identifying repeatable urban stability patterns, improvements to each of these impacted areas can be achieved. In this report, the *White Sands Missile Range (WSMR) Urban Study* research project is reviewed with a focus on stability characterization; specifically, the stable urban environment. Results from the *WSMR 2007 Urban Study* stability assessment are described and contrasted with the previous two urban studies. Eight stable environment characteristics were gleaned from the inter-*Study* analyses. The stable conditions observed showed an extremely consistent temporal pattern. The spatial distribution proved inconsistent however, the seasonally similar field studies showed patterns worthy of special note. Examples of the seasonally-similar stable patterns are given. A short summary of stable environment characteristics observed thus far are tallied in the Summary and several recommendations for subsequent research conclude the technical report. Preliminary results from the ongoing higher time resolution analysis are documented in appendix A.

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Contents

List of Figures

List of Tables

Acknowledgments

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Executive Summary

Urban atmospheric stability patterns impact military and civilian health, tools, operations, and strategic planning. By identifying repeatable urban stability patterns, improvements to each impacted area can be achieved.

In this report, the *White Sands Missile Range (WSMR) Urban Study* research project is reviewed with a focus on the stability characterization mission objective. Results from the initial two studies, *WSMR 2003 Urban Study* (*W03US)* and *WSMR 2005 Urban Study (W05US)* are presented as a foundation for subsequent comparisons. From these results, the general urban stability characterization objective was refined into a pursuit of the diurnal stable atmospheric patterns around a single office building. With the less understood stable patterns clarified, the overall stability cycles are expected to be more easily identified and explained. The most recent field study, *WMSR 2007 Urban Study* (*W07US),* continues with this refined objective. In Chapter 1, *W07US* is described in terms of mission objectives, site layout, and sensor selection. Chapter 2 provides a description of the *W07US* stability assessment with a focus on the stable environment evaluation. A comparison of stable patterns between all three field studies is given in the chapter 3. Eight noteworthy patterns are subdivided into spatial and temporal perspectives.

The spatial stable patterns were inconsistent across all three field studies. There was, however, consistency between seasonally similar field studies. For example, the spatial distribution during the climatologically windy field studies of *W03US* and *W05US* showed a preference of stable conditions on the east (leeside) of the subject building. The open environment of the east side suggested an increased potential for radiative cooling with respect to the other "enclosed" building sides. This cooling would subsequently favor stable environments.

The atypical climatological conditions (light winds) of the *W07US* favored the west (Fetch) side of the building. The proposed explanation for these contrasting results suggested that the heat from the radiating building lacked the airflow to bring the heat away from the building. Therefore, all sides, but the Fetch, integrated the added heat into the vertical profiles and reported less stable conditions than the non-building influenced Fetch (west) side.

The cross-field study evaluation of stable cases showed an amazing consistency in the average case length. On average, the consecutive minutes of a stable environment were between 6–8 min in length for all three *Studies*. Unfortunately, the maximum case durations between towers and field studies varied greatly, ranging from 14–312 min.

The temporal distribution of the stable environment between the three field studies was extremely consistent! The first preferred time period for occurrence was during the Nighttime period, 2100–0259 local time (LT). The second preferred was 0300–0859 LT (Sunrise). In two of the *Studies*, there was a third preferred period of 1500–2059 LT (Sunset).

In summary, the stable environment characteristics observed from all three *Studies* included:

- The most populated period for stable environment occurrence was midnight, ±3 h. (Preliminary findings from subsequent research indicate that the most populated period may be refined to 0000–0300 LT. A preview of these research results is included in appendix A.)

- Second most populated period for stable environment occurrence was sunrise, ±3 h.

- During windy conditions, the building leeside was favored.

- During non-windy conditions, the building windward (Fetch) side was favored.

- The average duration of consecutive minutes for stable conditions was 6–8 min.

- The extreme durations for consecutive stable minutes ranged from 14–312 min (312 min = 5 h 12 min).

- Extreme stable case durations favored the non-windy environments.

- The roof with a heating vent generated a stable environment.

Several recommendations for subsequent research conclude the technical report.

1. Background

Hazardous chemical and biological releases in an urban area are a threat to both civilian and military personnel alike. The U.S. Army Research Laboratory (ARL) is in the process of enhancing their current understanding of the urban atmosphere. One of the goals for this urban atmospheric research is to develop a tool which will help define and inform military and civilian persons of least hazardous or "safe" zones around a building. Two atmospheric elements that make critical contributions to the definition of an urban "least hazardous" location are atmospheric stability (which impacts airborne chemical/biological concentrations) and airflow (which impacts airborne chemical/biological dissemination). This report will focus on urban atmospheric stability.

In addition to urban emergency response applications, civilian and military health, tools, operations, and strategic planning are also impacted by the urban diurnal stability patterns. By knowing and exploiting repeatable urban stability patterns, improvements can be made in all of these impacted areas.

In ARL-TR-4256, Volume AS-1 (Vaucher, 2007), examples of urban stability impacts were provided, as well as a statistically and empirically derived characterization of a diurnal urban stability cycle. This characterization was gleaned from two independent urban study data sets entitled *White Sands Missile Range (WSMR) 2003 Urban Study (W03US)* and *WSMR 2005 Urban Study (W05US)*. Both field studies acquired data over a common single-subject-building test site. In 2007, a third more detailed field study, *WSMR 2007 Urban Study (W07US),* was conducted at this same field site, and will be one of the two main topics for this technical report.

In the following subsections, the *WSMR Urban Study* research project will be described, including a brief review of the earlier *Studies*' stability results and observations. An overview of the *W07US* concludes this section.

1.1 *WSMR Urban Study*

The mission objectives driving the *WSMR Urban Study* research covered a range of scientific, technical and applications areas. The two scientific objectives, which linked the three field studies, were as follows:

1. To characterize the stability patterns around and above a single urban building.

2. To characterize the airflow patterns around and above a single urban building.

These goals were selected based on the critical nature they play in diagnosing a hazardous chemical and/or biological release in an urban environment.

The field designs were based on physical (wind tunnel) and computer models. These models addressed both the stability and airflow patterns around and above a single urban building. In support of the stability characterization, the field design consulted the Ocean Breeze-Dry Gulch (OB/DG) atmospheric dispersion model. The OB/DG model is an U.S. Air Force Air Weather Service model used for predicting the hazard zones resulting from an accidental toxic chemical spill. (Defense Technical Information Center, 2008). The airflow portion of the 2003, 2005, and 2007 field designs was derived from a published Environmental Protection Agency (EPA)/ National Oceanic and Atmospheric Administrations (NOAA) wind tunnel study, which reported airflow streamlines around and above a single structure of varying proportions (Snyder and Lawson, Jr., 1994). In *W07US*, the airflow design also consulted ARL's diagnostic Three-Dimensional Wind Field model (3DWF). With the general stability and airflow patterns defined by the models, selecting a field site was the next major task. Section 1.2 will describe the test site.

1.2   *WSMR Urban Study* Test Site

The two key attributes needed for the urban study field site included a location in which the systematic heating/cooling diurnal cycles would be minimized and the airflow would be consistent and strong (high velocity magnitudes). According to southwestern US climatological reports, the greatest occurrence for strong sustained winds occur during the months of March and April. The solar equinox occurs in March; therefore, March at WSMR, NM, was selected for all three data acquisition periods.

The small complex of office buildings selected at WSMR, NM included a subject building that was two-stories tall, concrete-blocked, rectangular in shape, and had a nearly flat roof. A single story "doghouse" was perched on the south side of the roof. To the north of this subject building was a similarly constructed building of equal height; to the south was a single-story building; to the west was a stair-cased, 1- to 2-level building; and to the immediate east was a small plot of green tailored grass, followed by a sidewalk and a paved four-row parking lot. During the *W03US* data acquisition period, automobiles were confined to the farthest two parking lot rows and no vehicle traffic was permitted near the towers. In 2005, the test site layout included the farthest two parking lot rows. Thus, no automobiles were permitted access to this area during the *W05US* data acquisition. Two, two-story tall trees covered the northeast and southeast corners of the compass-aligned subject building during the 2003 and 2005 field studies. These trees were removed just prior to the 2007 field study. Bushes framed the front door area in all three *Studies*. Nearly level gravel and dirt surfaces were between buildings (figure 1). (Vaucher, 2007)

Figure 1. *W03US* building and tower placement.

Note: The *W05US* test site used this foundational configuration and added three tripods on the leeside of the
building. Note the trees on the northeast and southeast corners. These were removed just prior to *W07US*.

1.3   Data Resources

Data acquired during the three *WSMR Urban Studies* were aimed at characterizing both stability
and airflow patterns around the single urban office building. Therefore, sensor and tower
placements were based on optimizing stability and airflow pattern extraction.

In *W03US* (March 2003), data were acquired from four 10 m towers on each side of the subject
building, and a shorter 5 m tower on the roof. Figure 1 shows a side view photograph of the field
site. Figure 2 shows the overview perspective on the tower position layout relative to the subject
building. Tower orientation was angled to accommodate local prevailing wind directions. The
sensors selected included a barometer (Vaisala PTB-101B), thermometer (Campbell-T107),
thermometer/hygrometer (Vaisala-HMP45AC), anemometer (RM Young Wind Monitor-05103),
and pyranometer (Kipp/Zonen-CM3). A Campbell CR23X micro-logger recorded the standard
meteorological parameters in 1-min averages.
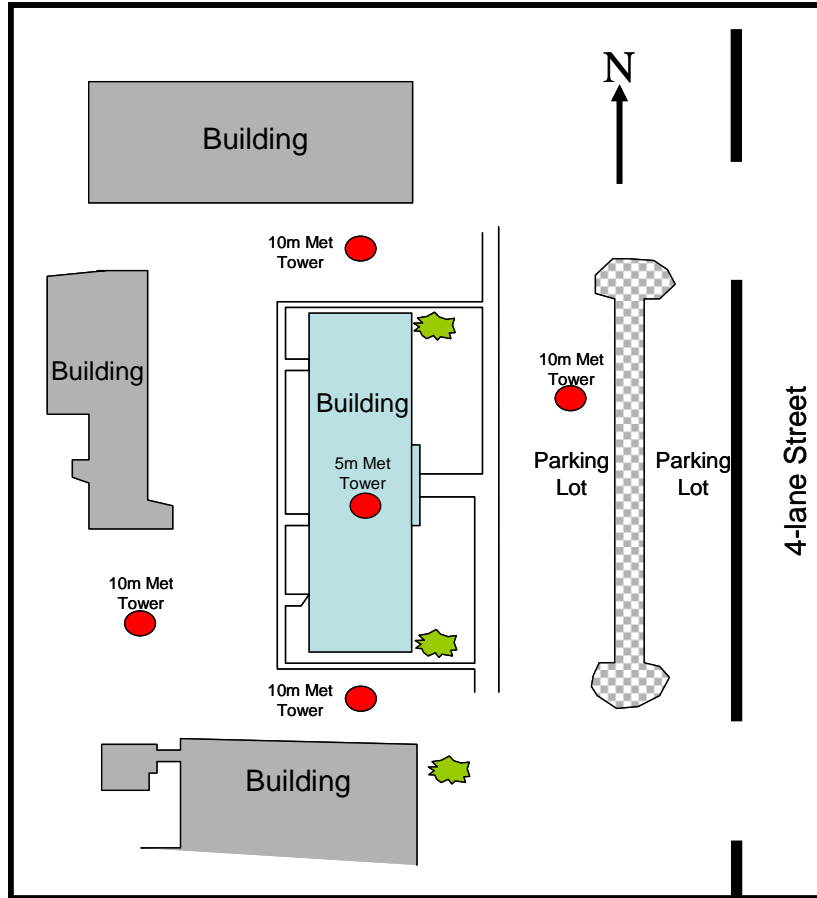
Figure 2. *W03US* field site layout.

Note: Gray areas represent buildings, with the subject building as blue; green
       jagged circles are trees; and red filled circles represent the towers. The
       layout is not drawn to scale.

Note: Each 10 m tower reference is labeled and referred to by its compass position relative to the single subject building. For example, the North tower is the 10 m tower placed on the north side of the subject building. The South tower is the tower placed on the south side of the building.

In the *W05US* field study, the original tower design remained the same and three tripods were strategically placed to quantitatively capture two additional airflow features: the leeside building Reattachment Zone and the two Leeside Corner Eddies (indicated by the arrows pointing to the X locations in figure 3). Campbell CR23X micro-loggers recorded 1-min mean data values on each tower. The turbulent airflow parameterization required RM Young ultrasonic anemometers (Model 81000) to be added to the 10 m towers at 10 m, 5 m, and 2.5 m above ground level (AGL). Thermodynamic data were sampled from the eastern side of the tower (optimizing sunrise effects), and the dynamic data of the ultrasonics were acquired from the tower's climatologically windward side (west). Solar sensors were positioned on the tower's south side. The Roof tower acquired sonic data at 5 m AGL and the three tripods sampled sonic data at 2 m AGL.
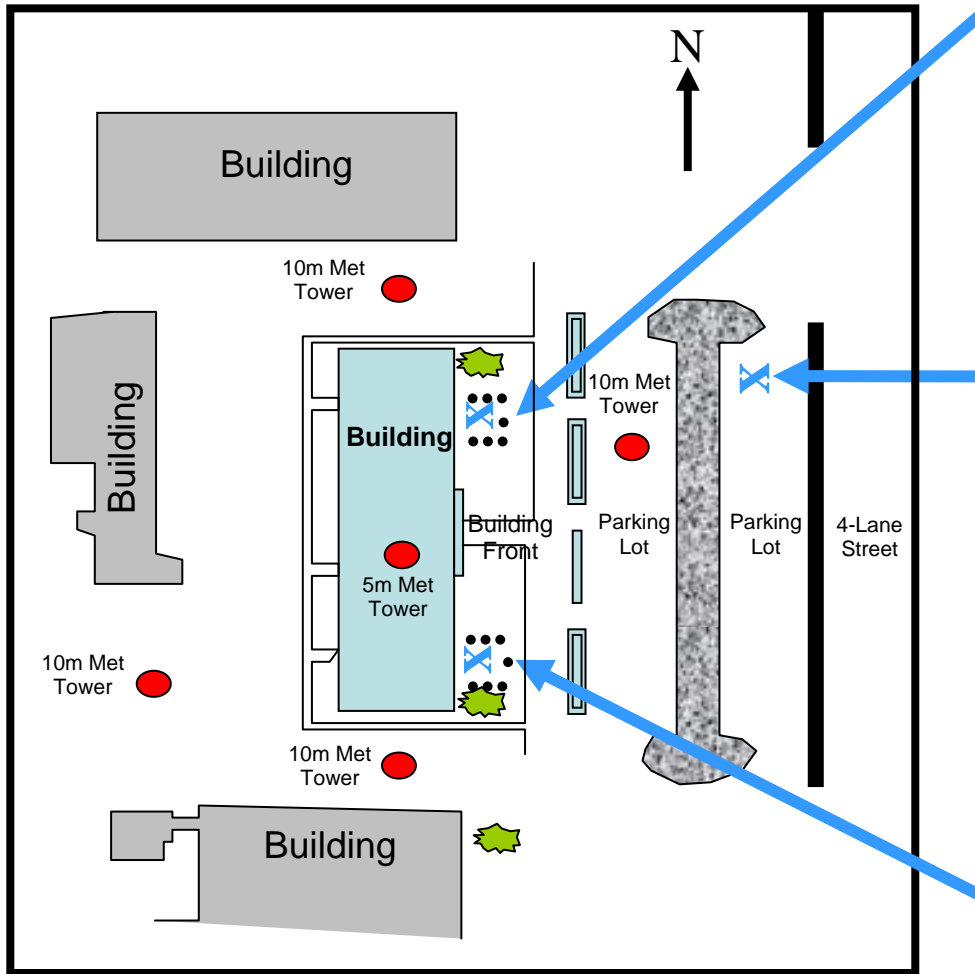
Figure 3. *W05US* field site layout.

Note: The layout is not drawn to scale.

1.4 Previous *Studies* Data Analyses and Results

The month of March (solar equinox) was selected for all three data acquisition periods in order to minimize the systematic effects of the diurnal heating/cooling cycle, and provide for the greatest probability for strong sustained winds. The actual weather pattern during both *W03US* and *W05US* acquisition periods ranged from calm clear skies to typical NM spring windstorms (winds sustained at greater than 10 m/s) due to tight pressure gradients aloft.

The initial stability characterization of *W03US* reported both rural (night-stable, day-unstable, two transitions-neutral) and urban-city (24 h of unstable or neutral/unstable) stability cycles. Therefore, the subsequent *W05US* stability characterization effort focused on just the atypical urban "stable" environment. The purpose for this approach was to first understand the idiosyncrasies of the less frequent stable pattern then return to the ill-defined diurnal urban cycle armed with enough information (pattern recognition) to extract a much more coherent picture of the two originally dichotomous conditions (rural and city cycles) observed around the small urban building complex.

The stability characterization analysis examined the stable data in terms of spatial and temporal patterns. The patterns were first measured in terms of "minutes of occurrences" and "percentage of a sample day in which the stable condition occurred." Then, to help describe the statistical distribution over extended stable periods, consecutive minutes of occurrence were grouped together into "cases." The resultant statistics became the baseline for comparison.

Note: A "stable case" is defined as when the vertical temperature differential ($T_{10\,m}$ minus $T_{2\,m}$) is greater than 1 °C for 1 or more minutes.

1.4.1 *WSMR 2003 Urban Study* Stable Data Analysis and Results

The initial *W03US* stability analysis searched for general diurnal urban cycles to contrast with the rural environment. As explained earlier, what was found displayed both the rural and urban-city stability patterns. Subsequently, a re-analysis of the data was conducted that focused on just the atypical stable environments. As per Volume AS-1 (Vaucher, 2007), the following were the results for *W03US*:

- The total days sampled per tower ranged from 7 and 9 days. On average, the tower data reported stable conditions occurring in 65% of the days sampled. The tower reporting the greatest number of minutes in a stable environment was to the east. The second greatest number of stable condition minutes was from the South tower. The least amount of stable minutes was reported by the North tower. Note: The North tower also sampled the fewest days (7 days).

- The average number of stable minutes ranged from 12–40 min/day, with large standard deviations. Coupling these statistics with a timeline perspective (see appendix B), one can see a grouping of stable environmental conditions. The maximum number of minutes in a single day paralleled the overall total minutes in stable conditions: the East tower reported a maximum period of 236 min in a single day, followed by the South tower (151 min), the West tower (75 min), and the North tower (47 min).

Grouping consecutive stable minutes together into cases, the longest duration for a case was 60 min, which occurred at the East tower. The South and West towers each showed 37 min for their longest case. The North tower reported the longest case to be 14 min. On average, a case was between 5–11 min in length (±4–14 min).

The stable patterns over a 24-h clock showed the period of greatest occurrence was between 2100 and 0259 Local Time (LT), followed by 0300–0859 LT. These two periods represent the Nighttime and Sunrise periods, respectively. As expected, no stable conditions were reported from 0900–1459 LT (Daytime). No stable conditions were observed between 1500–2059 LT (Sunset period).

Table 1 summarizes the *W03US* stable atmosphere statistics. Graphical summaries of the *W03US* spatial and temporal characteristics are provided in appendix B.

6

Table 1. Statistical summary of *W03US* stable conditions.

W03US Stable Conditions	West	South	North	East
Julian Day number sampled	83–90	71, 83–90	84–90	83–90
Percentage of days sampled in which stable conditions were reported	62%	67%	57%	75%
Total minutes in stable conditions	197	267	84	320
Average stable minutes per day	25 (±29)	30(±49)	12(±18)	40(±80)
Maximum number of stable minutes per day	75	151	47	236
Maximum number of cases per day	26	37	16	30
Average case duration (min)	7.6(±8.9)	7.2(±6.8)	5.3(±4.2)	10.7(±14.5)
Longest case duration (min)	37	37	14	60

1.4.2   *WSMR 2005 Urban Study* Stable Data Analysis and Results

The *W05US* stable environment data analysis results were described in Volume AS-1 (Vaucher, 2007) as the following:

- In *W05US*, there were approximately 19 days of data acquired. From these days, approximately 50% of the days sampled reported stable conditions from each side of the building. The total stable minutes observed was greatest in the East tower (663 min). The North tower reported about half as many minutes in a stable status. The South (195 min) and West towers (150 min) reported the least frequent occurrences.

- The average number stable minutes ranged from about 8–35 min, but these numbers only showed a partial picture. One needed to consider the standard deviation to see that there was significant clustering in portions of the stability timeline. Appendix C shows a much clearer picture of this timeline clustering through the graphical summaries.

- Converting the consecutive minutes of stable conditions into units of a "case," the average case duration statistically ranged from 4–10 min. However, the longest stable case duration was 54 min and was observed in the East tower data.

- Using a 24-h timescale, the time period with the greatest number of stable vertical profiles was between 2100 and 0259 LT (Nighttime period). The second most populated time period was between 0300 and 0859 LT (Sunrise period), followed by 1500–2059 LT (Sunset period). As expected, no stable samples were observed between 0900–1459 LT (Daytime). Subtle to these numerical observations was the presence of a mini-heat island effect surrounding the building.

Table 2 provides a statistical summary of *W05US* stable conditions. A graphical summary of the *W05US* spatial and temporal characteristics is in appendix C.

Table 2. Statistical summary of *W05US* stable conditions.

W05US Stable Conditions	West	South	North	East
Julian Day number sampled	76–94	76–94	76–94	76–94
Percentage of days sampled in which stable conditions were reported (number of days)	58% (11)	53% (10)	47% (9)	47% (9)
Total minutes in stable conditions	150	195	352	663
Average stable minutes per day	7.9 [±11]	10[±14]	18[±27]	35[±62]
Maximum number of stable minutes per day	36	52	86	238
Number of cases	41	44	58	83
Average case duration (min)	3.7 [±3.5]	4.4 [±3.4]	6.1 [±3.9]	8.0 [±10.7]
Longest case duration (min)	20	16	17	54

1.5 *WSMR 2007 Urban Study*

W07US was designed around the following mission objectives:

1. To acquire data for verification of urban micro-meteorology models, such as ARL's 3DWF model and   Los Alamos National Laboratory's (LANL) Quick Urban and Industrial Complex (QUIC) model.

2. To characterize behavior of turbulent airflow around and above a single building.

3. To characterize surface layer stability patterns in an urban environment.

4. To design, develop, test, and evaluate an integrated Data Acquisition System (DAS) hardware / software.

5. To evaluate sensor systems for a new mobile, modular, reusable Safari unit design.

6. To demonstrate disaster response applications for scenarios focused on a single office building.

These objectives stemmed from three general categories: urban characterization research (Objectives #1, 2, 3), technological advances (Objectives #4, 5), and applications (Objective #6).

The *W07US* physical field site began with the same basic layout and arrangements of the previous two studies. Then, to satisfy the mission objectives, more sensors were added, improved technology was integrated, and a more efficient system for acquiring, processing and communicating data was incorporated into the field execution. The final enriching innovation was the inclusion of urban disaster response application drills, which coincided with the atmospheric data acquisition. For more details on each of these improvements, see ARL-TR-4255 (Vaucher et al., 2007).

1.5.1 *W07US* Test Site Layout

The *W07US* field site consisted of the same subject building used in the previous two studies. Three similarly-constructed buildings were to the north, west and south of the subject building. To the east was a small, tailored grassy area; a four-row parking lot with a dividing walkway between rows 2 and 3; and a four-lane road. No vehicles were permitted to park in the parking areas during the data acquisition period. Figure 4 displays a plan view of the building domain. This top down view shows the positions for the 12 towers/tripods with respect to the subject and surrounding buildings. Compass north is at the top of the page. The triangles represent the three tower types: 12 m (blue), 10 m (red) and partial-10 m (yellow) towers. The black crosses indicate the 6 m and 2 m tripods. The black dots, surrounding the partial towers on the lee side of the subject building, were fence post positions. Tell-tail flags were attached to each fence post, thus enabling a real time visualization of the circular airflow in that region. The initial location for the aerosol (smoke) release is marked with a cloud-like symbol. The regional prevailing wind was westerly. The local prevailing wind flow went from the southwest to the northeast; thus, the slightly skewed orientation of the major towers.
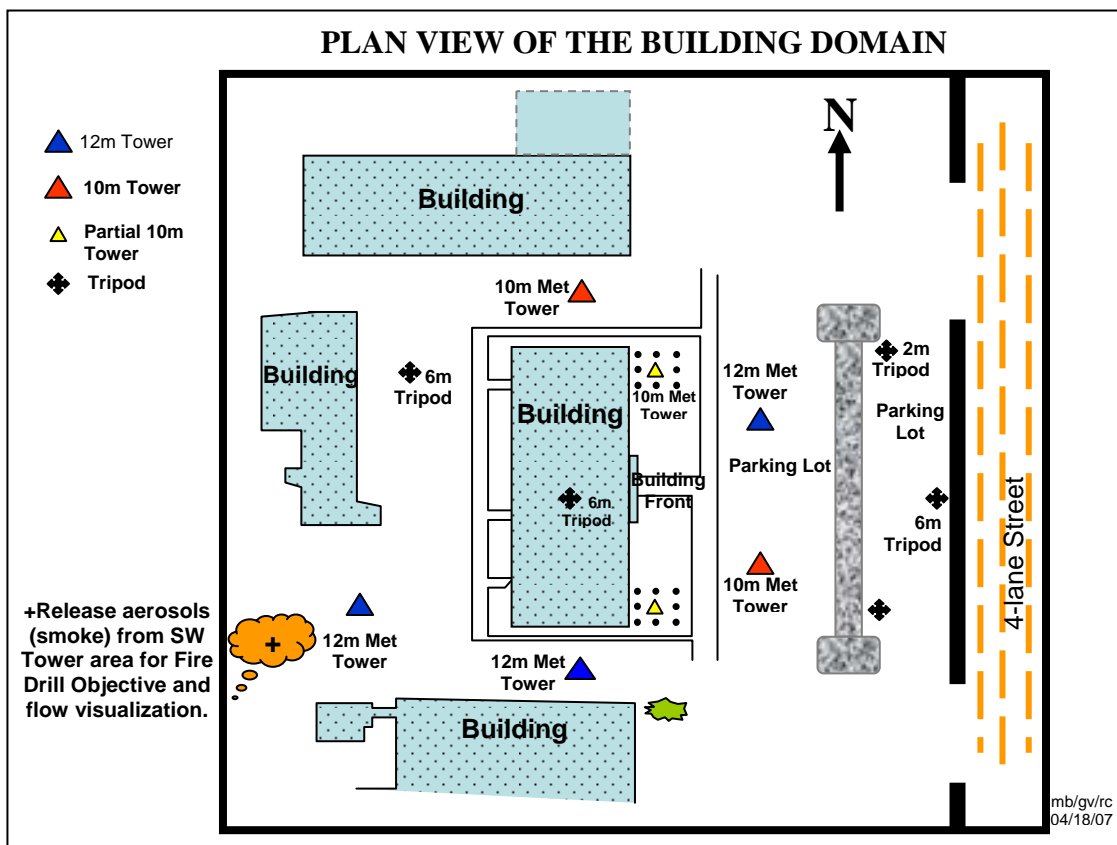

Figure 4. *W07US* field site layout.

Note: The black dots surrounding the partial 10 m towers are fence posts with tell-tail flags. The layout is not drawn to scale.

1.5.2 *W07US* Sensor Selection

Sensing stability patterns require thermodynamic data; therefore, the standard measurements of pressure, temperature, relative humidity, and solar radiation were acquired on all sides of the building. Unique to the *W07US* field design was the inclusion of three net radiometers, which were mounted on the Southwest, South, and Roof tower structures. These locations were selected based upon the experience gained from previous urban field studies, as well as the potential for gleaning a "building verses surrounding area" contrast in the net radiation.

In total, 51 sensors were required for this field study: 26 were linked to Campbell CR 23X micro-loggers (table 3) and 25 (RM Young Ultrasonic 81000 Anemometers) utilized wireless technology within their data logging system. The Campbell system sensors captured the thermodynamic/stability characterization measurements and were positioned on the east (sunrise side) and south sides of the towers/tripods. The Ultrasonic Anemometers were selected for their ability to quantify the dynamic characteristics of the urban airflow, and were mounted on the west side of the towers. The full tower/tripod configuration, for both the dynamic and thermodynamic data acquisition, is summarized in table 4.

Table 3. Mean flow measurements acquired by Campbell CR23X micro-logger systems.

Variable	Sensor	Manufacturer	Model	Units
Pressure	Barometer	Vaisala	PTB-101B	Millibars
Temperature	Thermometer	Campbell	T107	Celsius
Temperature/relative humidity	Thermometer/hygrometer	Vaisala	HMP45AC	Celsius/percent
Wind speed and wind direction	Wind monitor	RM Young	05103	Meter/second, and degrees
Solar radiation	Pyranometer	Kipp/Zonen	CM3	Watts/meter^2
Net solar radiation	Net radiometer	Kipp/Zonen	NR-LITE	Watts/meter^2

Table 4. *W07US* tower configuration.

Tower	Number of Units	Sensors: Sonics (/unit)	System: Campbell (/unit)
12 m tower	3	3 per unit	1 per unit
10 m tower	2	2 per unit	1. North: 1 2. Southeast: 0
Partial tower	2	1. Northeast: 2 2. Southeast: 3	0
6 m tripod	3	1. Roof: 1 2, 3.NWC, RE[a]: 2	1. Roof: 1 2, 3. NWC, RE[a]: 0
2 m tripod	2	1 per unit	0
Totals	12	25 sonic sensors	5 Campbell systems

[a]NWC = northwest canyon and RE = reattachment-east.

Each *W07US* tower was labeled by the compass position with respect to the subject building. For example, the North tower was north of the subject building. The Southeast tower was southeast of the subject building. Partial towers and tripods were labeled according to the airflow feature being captured and the compass location around the subject building. For example, the three tripods to the east of the building were called "Reattachment Zone-North," "Reattachment Zone-East," and "Reattachment Zone-South."

1.6   Reference Material for Additional Information

The *WSMR Urban Study* documentation has been evolving as the original researchers complete their investigations. The current reference materials available to the reader include the following:

1. ARL-TR-4255 (Vol.1): An overview of *W07US* design, preparations, field study execution.

2. ARL-TR-4439 (Vol. DP-1): Data Processing – Pre- and Post- *W07US* sonic calibration.

3. ARL-TR-4441 (Vol. DP-3): Data processing – airflow qualitative assessment.

4. ARL-TR-4256 (Vol. AS-1): A comparison of stability results from *W03US* and *W05US*.

5. ARL-TR-4452 (Vol. AS-2): Data processing – stability qualitative assessment, and inter-*Studies* comparison (this report).

2.   *W07US* Stability Data Analysis and Results

Note: All statistics reported in this section include the roof thermodynamic tower data. Previous *Urban Studies* did not have this data resource.

The *W07US* stability data was acquired over a period of approximately 19 days. On average, about 74% of these days reported stable conditions in one or more towers. The total number of stable condition minutes from all the towers was 6,430 min.

The spatial distribution for the observed stable environments was the following: The greatest number of stable minutes was observed in the West tower (1,724 min), followed by the Roof tower (1,510 min), the East tower (1,344 min) and the South tower (1,138 min). The least number of stable minutes was reported by the North tower (714 min). The average stable minutes per day ranged from about 38 min (North tower) to 91 min (West tower). All towers reported an exceptionally large standard deviation, implying strong clustering of stable events. Figure 5 shows these clustered stable conditions as a function of time.
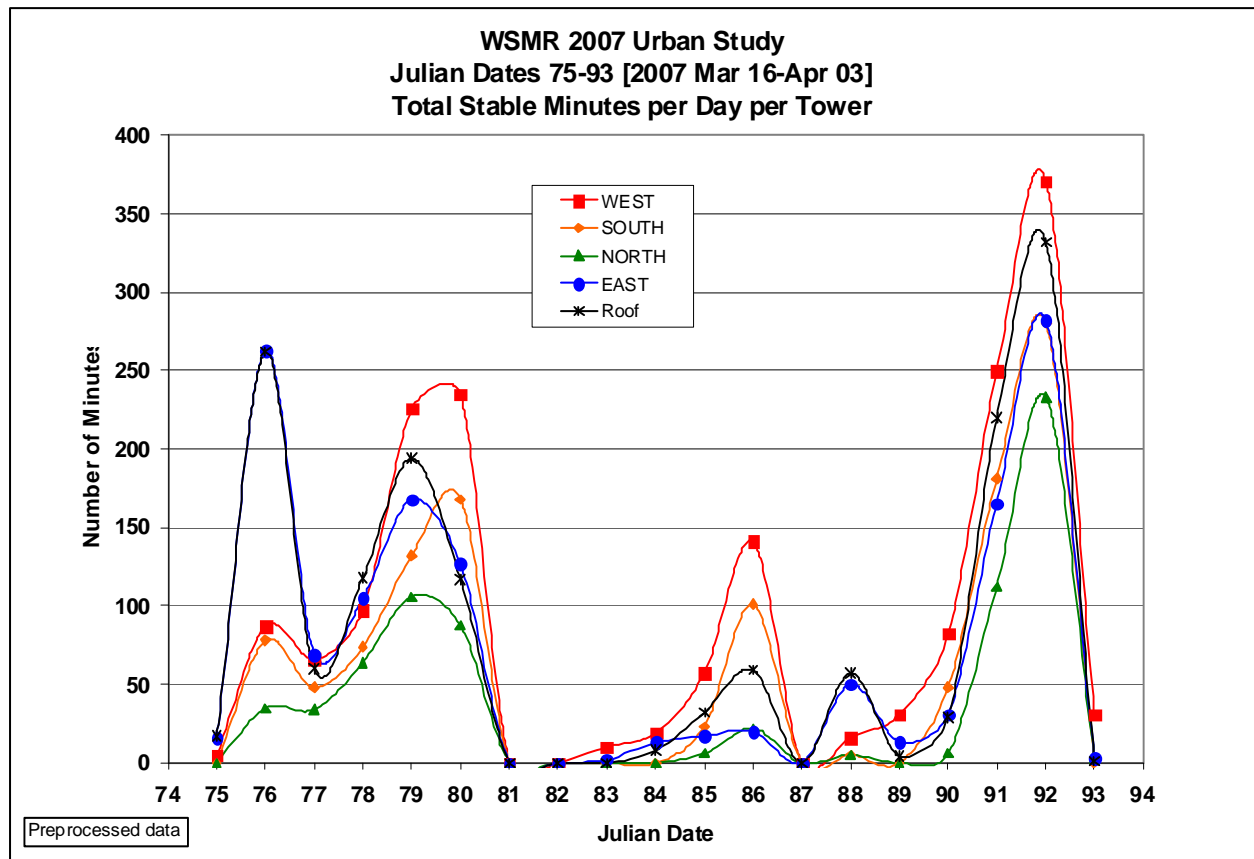
Figure 5. *W07US* total stable minutes per day per tower.

Converting the consecutive stable minutes into "cases," the average case duration was 8.6 min. The longest stable case occurred in the west tower and lasted 312 min, or 5 h and 12 min. Table 5 provides a statistical summary of the *W07US* stable conditions.

Table 5. *W07US s*tatistical summary of stable conditions.

W07US Stable Conditions	West	South	North	East	Roof
Julian Day number sampled	75–93	75–93	75–93	75–93	75–93
Percentage of days sampled in which stable conditions were reported (number of days)	84% (16)	58% (11)	63% (12)	84% (16)	79% (15)
Total minutes in stable conditions	1724	1138	714	1344	1510
Average stable minutes per day	91[±106]	60[±80]	38[±61]	71[±90]	80[±101]
Maximum number of stable min per day	371	280	233	282	332
Number of cases	159	136	111	166	175
Average case duration (min)	10.8[±26.9]	8.4 [±11.4]	6.4 [±5.9]	8.1 [±8.1]	8.6 [±17.0]
Longest case duration (min)	312	79	37	52	205

The temporal distribution of the stable conditions was evaluated by subdividing the 24-h clock into the following four periods: 0300–0859 LT (Sunrise), 0900–1459 LT (Daytime), 1500–2059 LT (Sunset), and 2100–0259 LT (Nighttime). The stable minutes were then tallied by period.

The most populated stable condition period was from 2100–0259 LT (Nighttime). All towers reported this period as having the greatest occurrence. Approximately two-thirds, or 67%, of the stable minutes fell within this time interval. The second greatest occurrence was from 0300-0859 LT (Sunrise). Again all towers consistently reported about 26% of their stable data within this time period. From 1500–2059 LT (Sunset), the average occurrence in all towers was 7%. No stable conditions were reported from 0900–1459 LT (Daytime).

Figure 6 graphically displays the temporal distribution of the *W07US* stable condition occurrences. Additional graphical summaries are provided in appendix D.
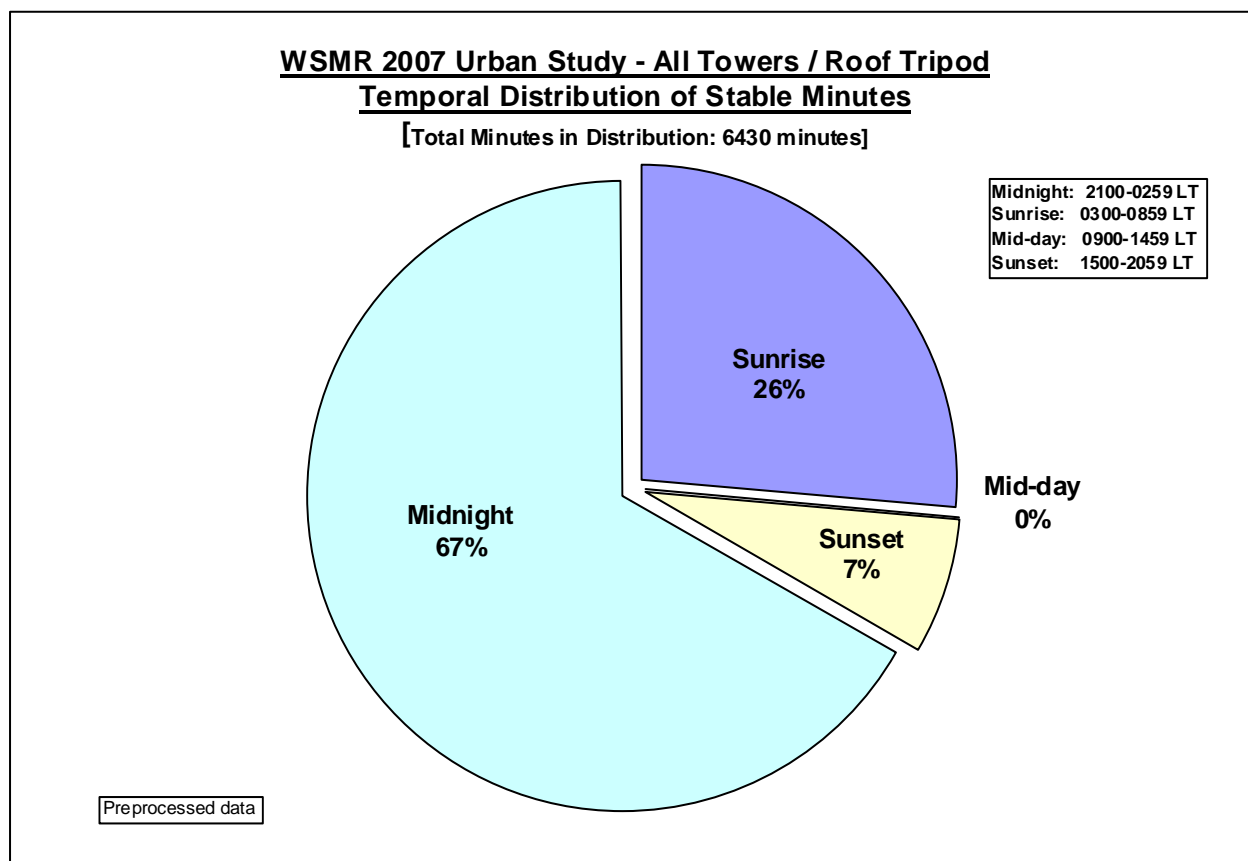

Figure 6. Time distribution of the *W07US* stable condition occurrences.

3. Comparison of the *W03US, W05US*, and *W07US* Stable Analysis Results

Comparisons of the *W07US* results with the earlier studies required some systematic adjustments. For example, *W03US* acquired data over a 9-day period, whereas *W05US* and *W07US* acquired data over an approximately 19-day period. For this reason, the answer to "how often was a stable environment present" was answered in proportion to the days sampled. That is, the results were as follows:

- Approximately 50% of the *W03US* days sampled reported stable conditions.

- Approximately 65% of the *W05US* days sampled reported stable conditions.

- Approximately 75% of the *W07US* days sampled reported stable conditions.

Another systematic difference impacting inter-*Study* comparisons was the following: The first two studies utilized thermodynamic data from four towers surrounding the subject building, whereas the *W07US* added a fifth thermodynamic data resource on the roof. Thus, the influences of this fifth resource (the Roof tower) on the statistical comparisons will be flagged where appropriate.

The inter-*Studies* analyses were subdivided into two distinct perspectives: the spatial and temporal stable condition characteristics. The ultimate goal of these comparisons is to extract a repeatable pattern useful in defining an urban diurnal stability cycle.

3.1 Spatial Comparisons

1. Is there a preferred side of a building for stable atmospheric conditions?

The three field studies sampled stability data around a north-south aligned subject building during the equinox time period. Theoretically, this arrangement should have minimized any systematic solar heating/cooling influences.

Comparing the spatial distribution of stable conditions across the three field studies, there were no fully consistent patterns. In table 6, the tower table-cell with the greatest percentage of stable minutes during each field study was filled with red. The second greatest was filled with orange, third with yellow, fourth with green, and finally, the last was filled with blue (following the longer to shorter wavelength color spectrum). If only the first two field studies were considered, a natural observation would be that the East tower was the preferred stable side. The open parking lot and a four-lane street to the east of the subject building would certainly support this observation, with its potential for radiative cooling overnight. Unfortunately, with the *W07US* results, the east side ranked second without the Roof data, and third, when the Roof data was included.

Table 6. Inter-*Study* Comparison: Percentage of stable minutes reported by tower.

Percentage of Stable Min by Tower	W03US	W05US	W07US No Roof Data Included	W07US Roof Data Included
East	36	49	27	21
South	31	14	23	18
West	23	11	35	27
North	10	26	15	11
Roof	N/A	N/A	Not Included	23

One possible explanation for the discontinuity between field studies involves the overall atmospheric conditions exhibited during the *Studies*. During *W03US* and *W05US*, the field site experienced typical climatologically windy conditions. With strong winds, the atmosphere tended to be well mixed. During *W07US*, periods of strong winds occurred but were not as frequent as the previous studies. Without these strong winds, the opportunity for a stratified vertical profile would have increased. The less dynamic and more buoyant atmosphere around the building would have subsequently integrated the building's heat into the local environment. Therefore, the potential for a stable atmosphere would have decreased around and downwind from the building. For *W07US*, this latter condition would have been on the north, south, and east of the subject building. The only side not injected with the subject building's heat would have been the Fetch side. The Fetch for *W07US* was on the west, which reported the greatest occurrence of stable conditions.

2. Why would the W07US Roof data rank second, after the west side, with regard to the greatest percentage of stable minutes sampled?

One possible explanation draws from the observation that to the north and west of the Roof tower was a building heating vent. Since neither dismantling nor turning off the building's heating system were options, the Roof tower placement was such that the heating vent's exhaust would be carried away from the building along a path well removed from the Roof tower. This strategy was based on the anticipated, climatologically strong, westerly winds, coupled with the locally forced southwesterly winds. As discussed earlier, *W07US* did not experience the typical strong NM winds. The prevailing wind direction was still westerly, though. Unfortunately, without the anticipated air movement to carry the heat away, the atmosphere over the roof may have gained a pocket of warm air that could have been picked up by the Roof's upper level sampler. The net result would have shown the lower level Roof sensor as relatively cooler than the upper level. Thus, a stable roof environment would have been reported.

3. What is the average number of stable minutes per day?

Table 7 shows the average number of stable minutes per day by tower and field study. Once again, the results were color coded from most to least frequent using the sequence of red, orange, yellow, green, and blue. Unfortunately, there were no consistent patterns apparent between all three field studies.

Table 7. Inter-*Study* Comparison: Average stable minutes per day.

Average Stable Min/Day	W03US	W05US	W07US No Roof Data	W07US Roof Data Included
West	25	8	90	90
South	30	10	60	60
North	12	18	38	38
East	40	35	71	71
Roof	N/A	N/A	Not included	80

Comparing the relative order of average magnitudes in Table 7, *W03US* and *W05US* showed the highest average in the East tower, but didn't agree with the rest of the order. They also showed a consistent 5 min/day drop in the maximum and minimum average values. *W07US* (without the Roof data) had a unique preference for the highest average (West tower) and the second place average (East tower), but then agreed with the *W05US* that the South tower ranked third place (South tower) and with *W03US*'s reporting of the fourth place (North tower). These results were consistent with table 6. No significant correlations could be made when including the Roof data.

Regarding the distribution of average consecutive stable values, the top three positions in *W03US* and *W07US* (no Roof data) showed a clustering of values with a sharp drop in magnitude for the lowest average. Even when the roof was included, the pattern of clustered values with a sharp drop in the last location remained in tact.

Table 8 shows the maximum number of stable min/day by tower and field study. These followed the same ordering as the averages presented in the preceding table.

Table 8. Inter-*Study* Comparison: Maximum number of stable minutes per day.

Maximum number of Stable Min/Day	W03US	W05US	W07US No Roof Data	W07US Roof Data Included
West	75	36	371	371
South	151	52	280	280
North	47	86	233	233
East	236	238	282	282
Roof	N/A	N/A	Not included	332

4. How often do consecutive stable conditions occur in a day and what is the average duration for these consecutive stable conditions?

To answer these questions, the consecutive stable minutes were grouped together into "cases." This action addresses the characterizing questions once the latter inquiry is reworded into "what is the average duration of a case?"

The number of stable cases per day is tabulated in table 9. Before examining table 9, the reader is reminded that the *W03US* data acquisition period was for only 9 days and the other two studies were roughly 19 days in length. This observation would help explain why the number of cases per day for *W05US* was about twice the magnitude as *W03US*. The larger jump in number of

cases between *W05US* and *W07US* was explained earlier in the discussion about the climatologically typical windy conditions for the first two studies and the atypical climatological conditions (less wind events) observed during *W07US*. These statistical results simply reinforced the influential nature of dichotomous seasonal environments. They also suggest that running this same field study under purposefully buoyant conditions could greatly enrich our understanding of the urban environment.

Table 9. Inter-*Study* Comparison: Number of stable cases per day; a "case" is comprised of two or more consecutive minutes of stable conditions.

Number of Cases/Day	W03US	W05US	W07US No Roof Data	W07US Roof Data Included
West	26	41	159	159
South	37	44	136	136
North	16	58	111	111
East	30	83	166	166
Roof	N/A	N/A	Not included	175

Before addressing "how often the stable conditions occur," a look at the average case duration is useful. Table 10 summarizes the average case duration by tower and field study. The intriguing observation here was that despite the contrasting climatological conditions between field studies, the overall average case duration was fairly consistent between all three field studies. *W05US* reported the average duration to be about 6 min, and both *W03US* and *W07US* showed their averages to be about 8 min (with and without the Roof data).

Table 10. Inter-*Study* Comparison: Average stable case duration in minutes.

Average Case Duration (min)	W03US	W05US	W07US No Roof Data	W07US Roof Data Included
West	8	4	11	11
South	7	4	8	8
North	5	6	6	6
East	11	8	8	8
Roof	N/A	N/A	Not included	9

The next question for assessing the character of the stable condition occurrence addresses the outer extremes. The longest stable case durations by tower and field study are summarized in table 11. Across the three studies, there were no truly consistent preferences. Grouping the first two field studies together, the highest duration was reported in the East tower. This was not surprising in light of the previous tables. The ranking of the second longest duration was also equivalent between the first two S*tudies*, though the magnitudes were not very close.

The North tower consistently reported a low magnitude of minutes in this longest case duration table (with and without the Roof data). These results remain a puzzle, considering that one would expect the north side of a building to favor cooler and therefore, stable air. Perhaps the fact that the subject building's north side was also a canyon flow area (accelerated flow through

17

a narrowed passageway) may explain the lack of stable preference over the other subject building sides. That is, an accelerated flow through a narrowed passageway would tend to generate a well-mixed (non-stable) atmosphere.

Table 11. Inter-*Study* Comparison: Longest stable case duration by tower.

Longest Case Duration (min)	W03US	W05US	W07US No Roof Data	W07US Roof Data Included
West	37	20	312	312
South	37	16	79	79
North	14	17	37	37
East	60	54	52	52
Roof	N/A	N/A	Not included	205

3.2 Temporal Comparisons

The temporal character of the stable environments was amazingly consistent across the three field studies. Using the four-quadrants of a 24-h clock, all field studies reported the most populated period of stable minutes to be during the Nighttime, between 2100–0259 LT. Likewise, the second most populated time period was consistently reported during the Sunrise Period (0300–0859 LT). The percentages reported in table 12 were calculated with respect to the total number of stable minutes reported for each particular field study. The consistency of proportions for each of the quadrants across the three field studies was most encouraging, especially in the context of unveiling an urban diurnal stability pattern. Since the pattern was so consistent, the next step already being pursed is to subdivide the time quadrants and extract a more finely tuned pattern of stable condition occurrences. The preliminary findings from this higher time resolution distribution are presented in appendix A. A future publication will document the more complete results.

Table 12. Inter-*Study* Comparison: Temporal distribution, in percentage, of stable conditions around the subject building.

Field Study	Sunrise 0300–0859 LT	Daytime 0900–1459 LT	Sunset 1500–2059 LT	Night Time 2100–0259 LT	Total (%)
W03US	44	0	0	56	100
W05US	44	0	6	50	100
W07US	28	0	6	66	100

4. Summary and Conclusions

Urban atmospheric stability patterns impact military and civilian health, tools, operations, and strategic planning. By identifying repeatable urban stability patterns, improvements to each area of impact can be achieved.

In this report, the *WSMR Urban Study* research project was reviewed, with a focus on the stability characterization mission. Results from the first two studies, *W03US* and *W05US,* showed a mix of rural and city stability patterns around the common field study's subject building. Therefore, the stability characterization objective was refined into a pursuit of the diurnal stable atmospheric pattern around an office building. By first understanding the idiosyncrasies of the less frequent urban stable pattern, researchers can then return to the ill-defined diurnal urban cycle armed with enough information (pattern recognition) to extract a much more coherent picture of the two originally dichotomous conditions (rural and city stability cycles) observed around the small urban building complex.

The *W07US* stability characterization continued with the stable analysis strategy. The subsequent results from the stable qualitative assessment were presented in chapter 2. Chapter 3 compared the *W07US* outcome against the earlier two field studies, subdividing the results into spatial and temporal perspectives.

While no spatial patterns proved consistent among all three field studies, there was consistency between seasonally similar field study atmospheric environments. For example, the spatial distribution during the climatologically windy field studies showed a preference of stable conditions on the east (leeside) of the subject building. The open environment of the east side suggested an increased potential for radiative cooling with respect to the other "enclosed" building sides.

The atypical climatological conditions (light winds) of the *W07US* favored the west (Fetch) side of the building. The proposed explanation for these contrasting results suggested that the heat from the radiating building lacked the airflow necessary to send the heat away from the building. Therefore, all sides but the Fetch integrated the added heat into the vertical profiles and reported less stable conditions than the non-building influenced Fetch (west) side.

The inter-*Study* evaluation of stable cases showed an amazing consistency in the average case length. On average, the consecutive minutes of a stable environment were between 6–8 min in length. Unfortunately, the maximum case durations between towers and field studies varied greatly, ranging from 14–312 min. For military tools that utilize stable urban environments, the cause for the persistent 312 min case would be of great interest.

The temporal distribution of the stable environment between the three field studies was extremely consistent! The first preferred time period for occurrence was 2100–0259 LT (Nighttime). The second preferred was 0300–0859 LT (Sunrise). In two of the *Studies*, there was a third preferred of 1500–2059 LT (Sunset). No *Study* reported stable conditions during the Daytime period (0900–1459 LT).

In short, the stable environment characteristics that have been observed thus far were:

1. The most populated period for stable environment occurrence was midnight, ±3 h.[*]

2. Second most populated period for stable environment occurrence was sunrise, ±3 h.

3. During windy conditions, the building leeside was favored.

4. During non-windy conditions, the building windward (Fetch) side was favored.

5. The average duration of consecutive minutes for stable conditions was 6–8 min.

6. The extreme durations for consecutive stable minutes ranged from 14–312 min (312 min = 5 h 12 min).

7. Extreme stable case durations favored the non-windy environments.

8. The roof with a heating vent generated a stable environment.

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5. Recommendations

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1. *Diurnal stability cycle*: The next step in the stability analysis is to investigate the spatial distribution under purposefully non-windy conditions. Such ambient scenarios favor the generation of a stable environment and would therefore better expose the diurnal cycle of the stability.

2. *Roof stable environments*: The anthropologically induced stable environment on the roof may prove useful to those who need to exploit stable environments. A more detailed review of the roof conditions during the data acquisition period may better define the causes and effects involved in generating the urban stable conditions.

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[*]Preliminary findings from subsequent research indicate that the most populated period may be refined to 0000–0300 LT. A preview of these research results is included in appendix A.

3. *Temporal stable environment character*: The next step, which is already being investigated by the current researchers, involves tightening the temporal scale of the stable distribution. Preliminary results of this finer-scaled distribution are included in appendix A. The intent is to better expose the diurnal stable trends and influences, which will ultimately lead to a forecastable urban diurnal stability pattern.

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    (accessed March 3, 2008).

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Vaucher, G.T.; Brice, R.; D'Arcy, S.; Bustillos, M.; Cionco, R. *White Sands Missile Range 2007 Urban Study: Data Processing - Volume DP-1 (Sonic Calibration)*; ARL-TR-4439; U.S. Army Research Laboratory: White Sands Missile Range, NM, In publication.

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Vaucher, G.T.; Bustillos, M.; Brice, R.; D'Arcy, S.; Cionco, R.; Chamberlain, F.; Trammel, J.; Luces, L.; Padilla, R.; Yarbrough, J. *White Sands Missile Range 2007 Urban Study: Flow and Stability Around a Single Building, Volume 1 (Field Study Overview)*; ARL-TR-4255; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2007.

Appendix A. A Preliminary Inter-*Study* Comparison of Stable Occurrences Using an Hourly Resolution

The summary section highlighted one of the most promising leads toward an urban diurnal stability pattern, namely the highly consistent nature of the stable conditions time distribution. The most populated period for stable conditions over the four quarters of a 24-h clock was from 2100–0259 LT (Nighttime). The second most populated period was from 0300–0859 LT (Sunrise). Though not consistent across all three field studies, the third favored period was from 1500–2059 LT (Sunset). No stable conditions were reported from 0900–1459 LT (Daytime).

Based on the above results, the author suggested subdividing these populated periods into smaller time intervals. Figures A-1 through A-3 are the preliminary results from this suggestion. All three figures utilize time on the *x*-axis, beginning at 1500 LT and ending at 0859 LT. Each subdivision represents a 0 to 59-min period. The unpopulated period of 0900–1459 LT was excluded. A stacked histogram, representing all the field study towers, provides a better picture of the cumulative occurrence. Each stacked histogram is color coded by tower as follows: Roof (red), East (yellow), North (green), South (blue), and West (indigo) towers.

Figure A-1 shows the tallies for *W03US*. Based on this hourly subdivision, the 9-day field study favored the period between 2300–0500 LT. Modest values were still present in the hour preceding and the two hours following this favored period. The MOST populated period was 0100 LT, with a close second during the 0200 LT hour.

Figure A-2 presents the tallies for *W05US*. The approximately 19-day study shows the hourly periods with 50 or more cumulative minutes to be between 2000–0600 LT. The times in which 100 or more minutes occurred were during two periods: the single hour of 2100 LT and the period of 0100–0400 LT. The over 150 min was between 0200–0400 LT. The MOST populated hour was during the 0300 LT hour.

Figure A-3 reports the tallies for *W07US*. Even without the Roof data, the cumulative magnitude reinforces an approximate increase of four times the earlier studies with respect to amount of stable minutes reported. With the Roof data, those hours in which over 100 min of stable conditions were present ranged from 1900–0600 LT. The most favored period (greater than 600 cumulative minutes) was between 2300–0300 LT. Preceding this highly populated period, is a gradual, consistent increase from 1900–2200 LT. After the highly populated period, there is a sharp drop for two hours and a curious increase in occurrence during the 0600 LT hour. The 0600 and 2200 hours were similar in magnitudes. For *W07US,* the MOST populated hour was 0100 LT.

This analysis is still in progress; however, these current results would seem to imply that the previous study's strong preference for 2100–0300 LT can be refined. Based on the hourly results and a subjective opinion, the new period favoring stable conditions might be defined as between 0000–0300 LT.
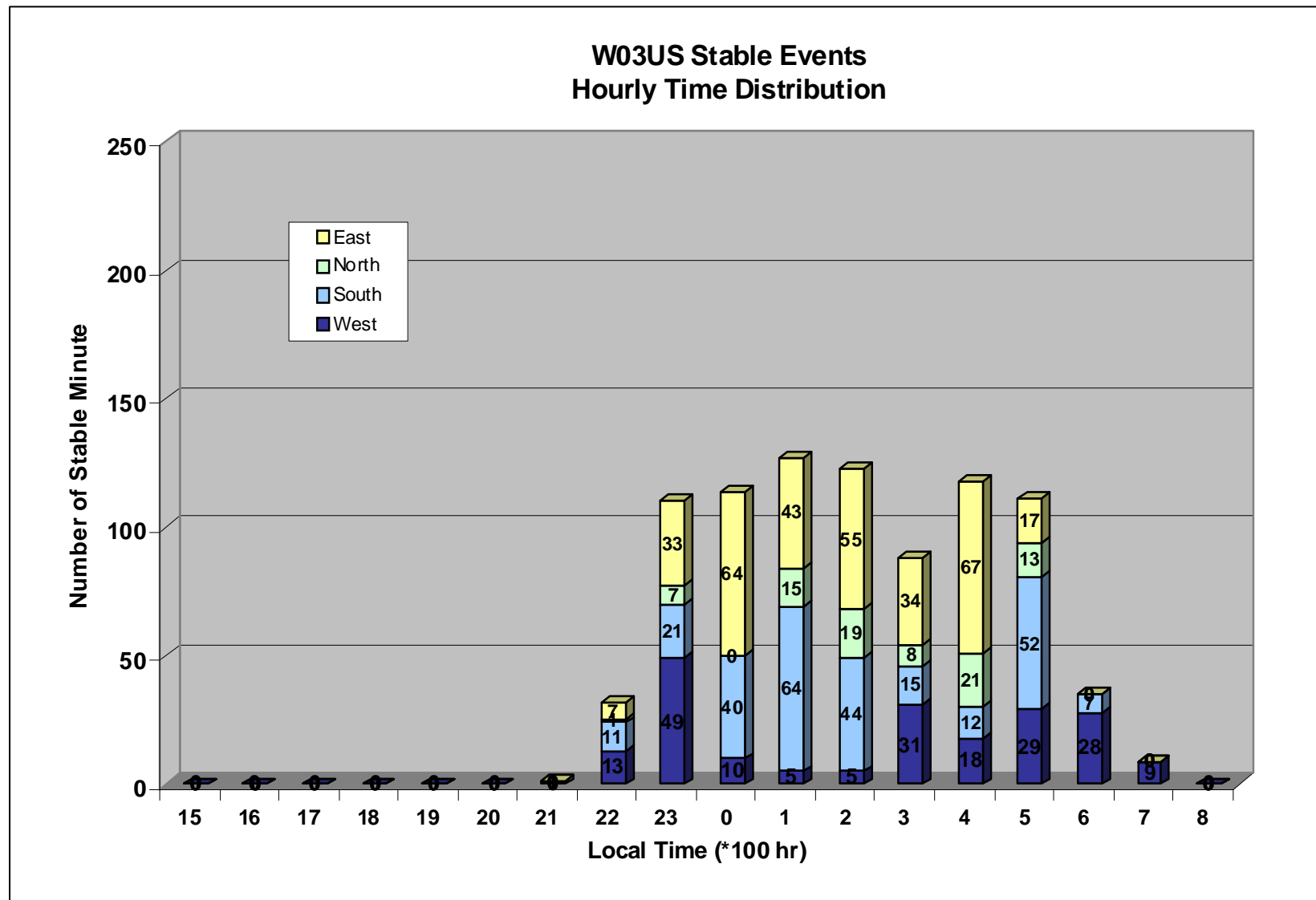
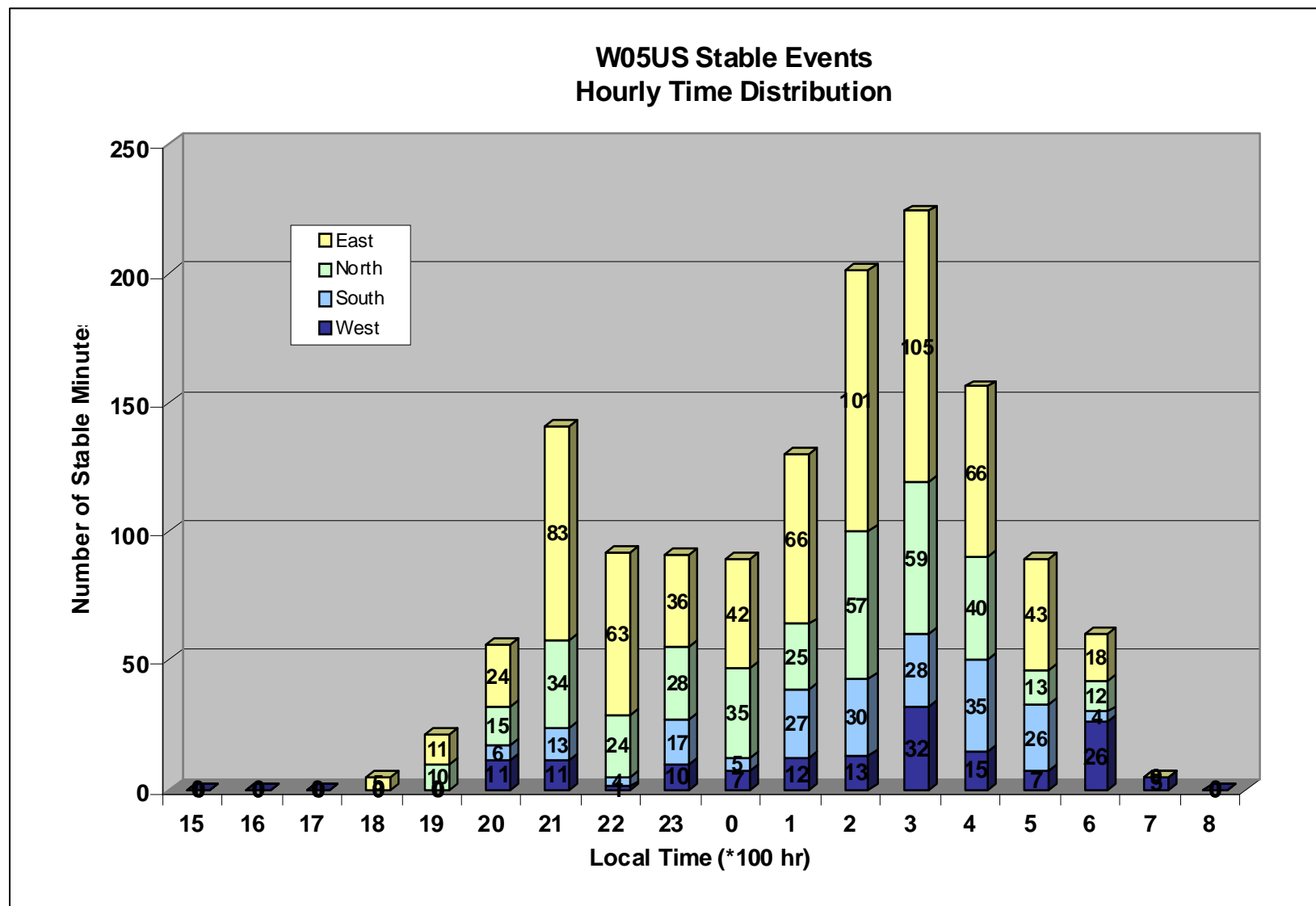Figure A-1. *W03US* stable events hourly time distribution.
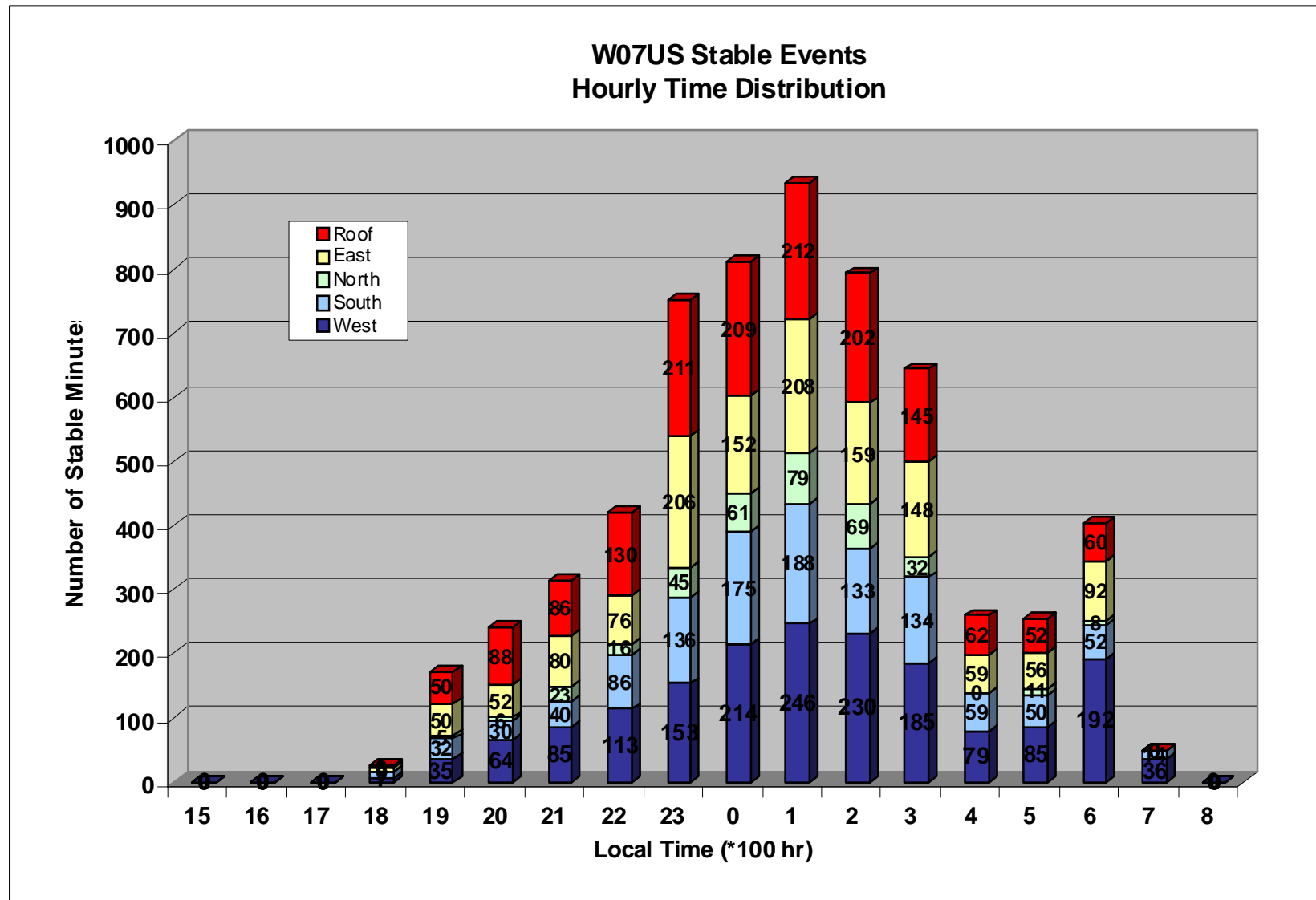
W05US Stable Events
Hourly Time Distribution

Figure A-2. *W05US* stable events hourly time distribution.

Figure A-3. *W07US* stable events hourly time distribution.

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Appendix B. *WSMR 2003 Urban Study* – Stable Characterization

Appendix B provides the key *W03US* graphical summaries used in the stable atmospheric characterization inter-comparison (Vaucher, 2007).

WSMR 2003 Urban Study
Percent of Stable Min by Tower
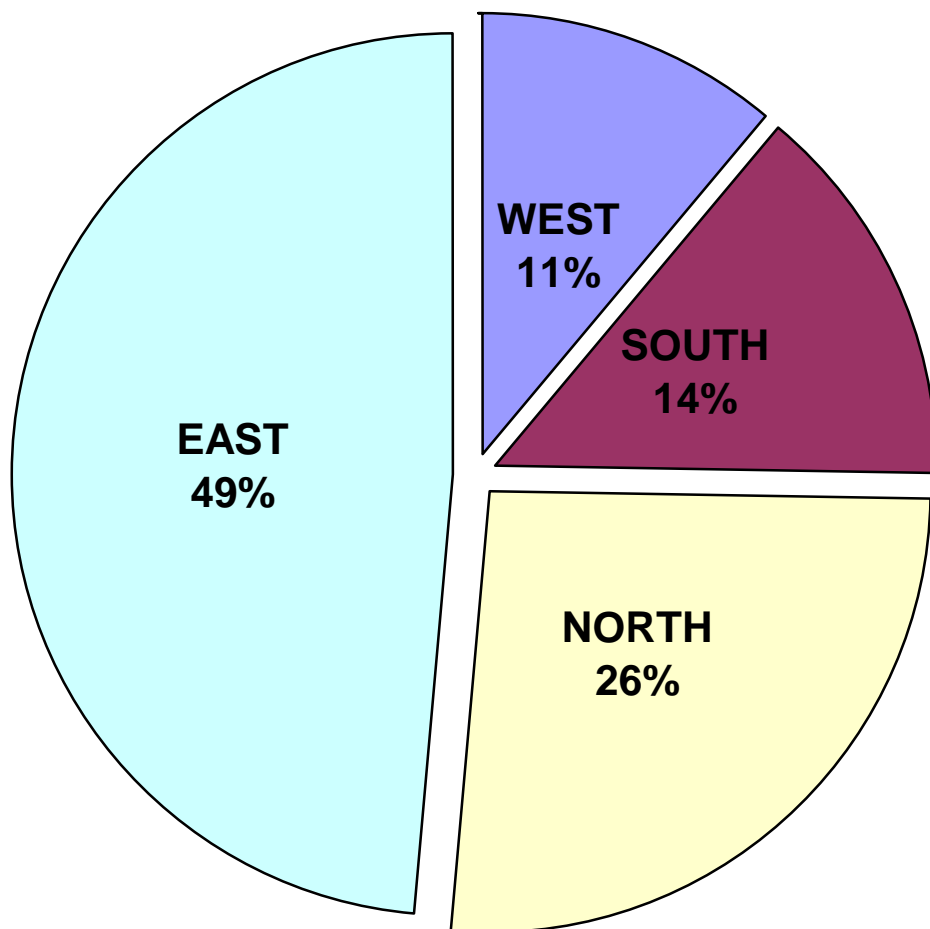[Total stable minutes reported: 868 minutes]
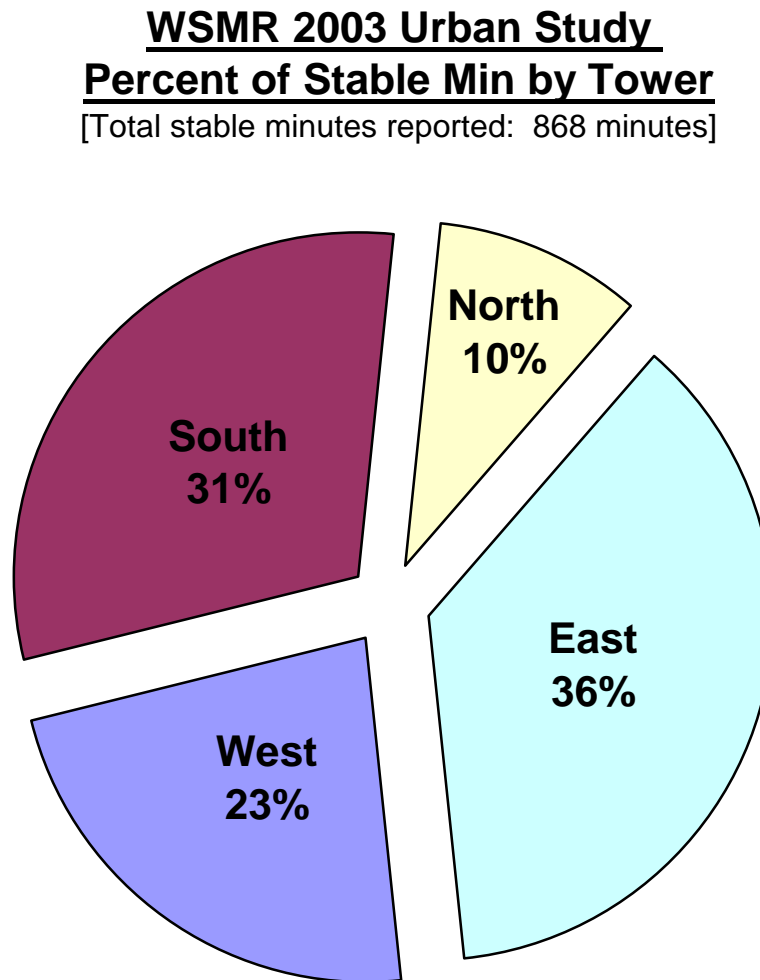
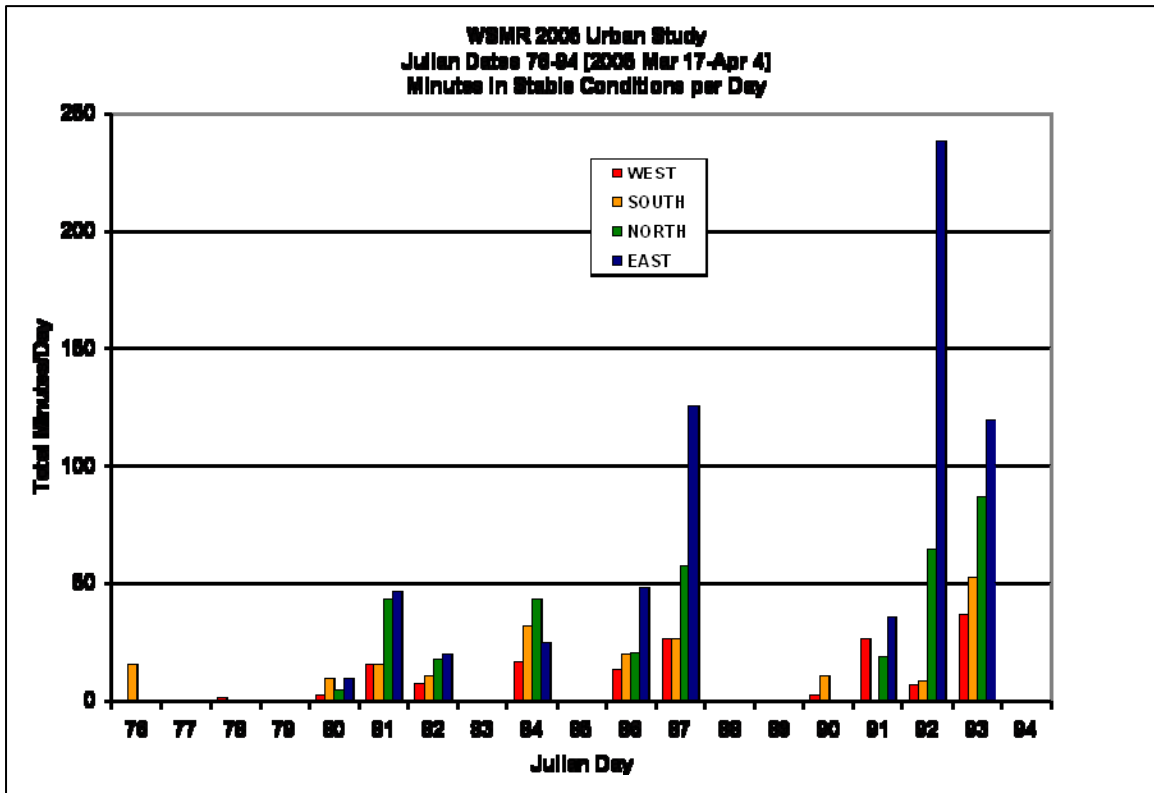Figure B-1. Percent of stable minutes by tower for the *W03US*.
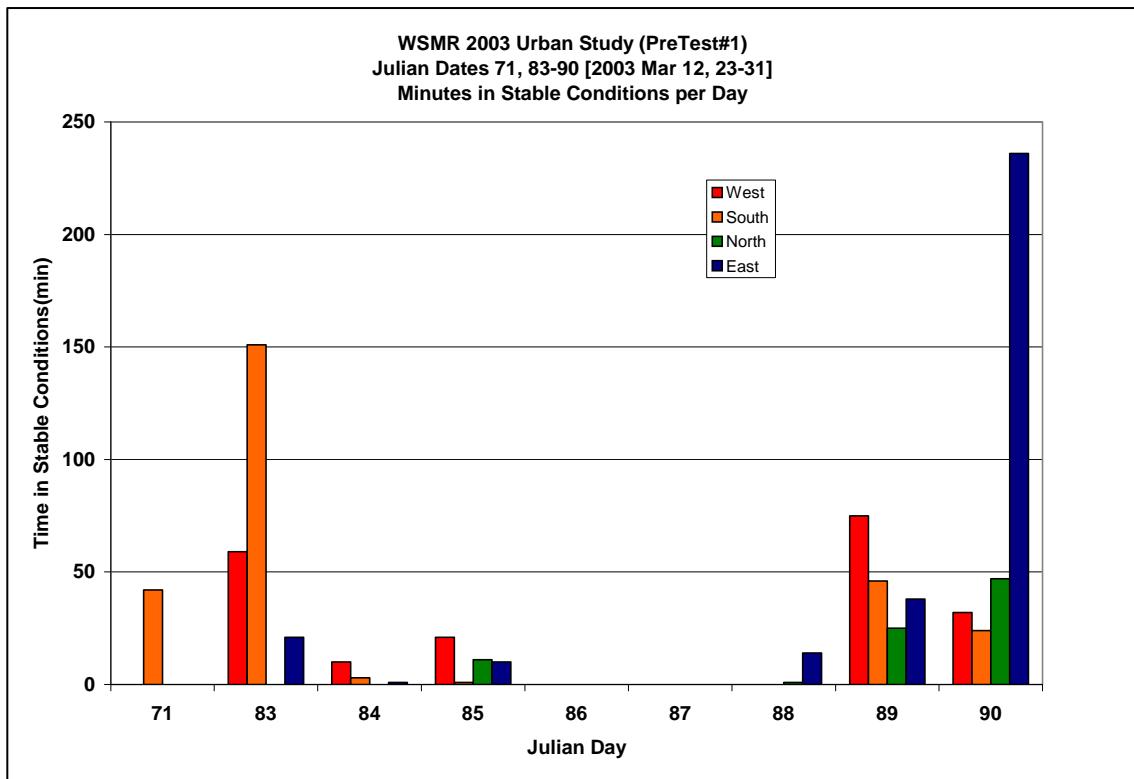
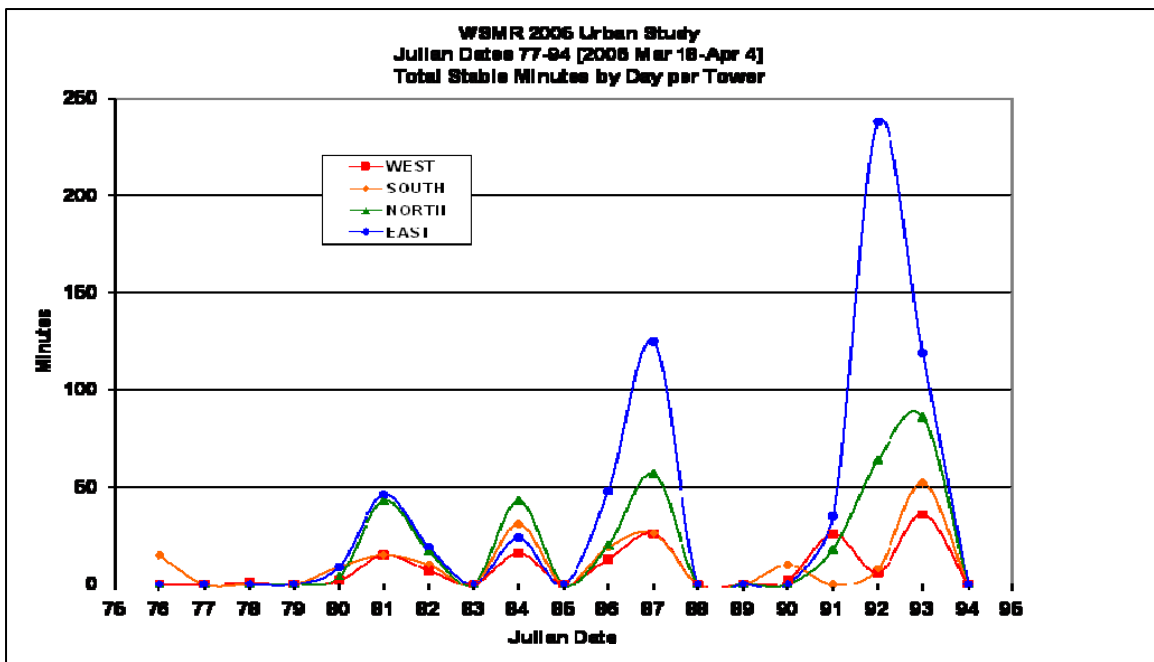Figure B-2. Minutes in stable condition per day for the *W03US*.
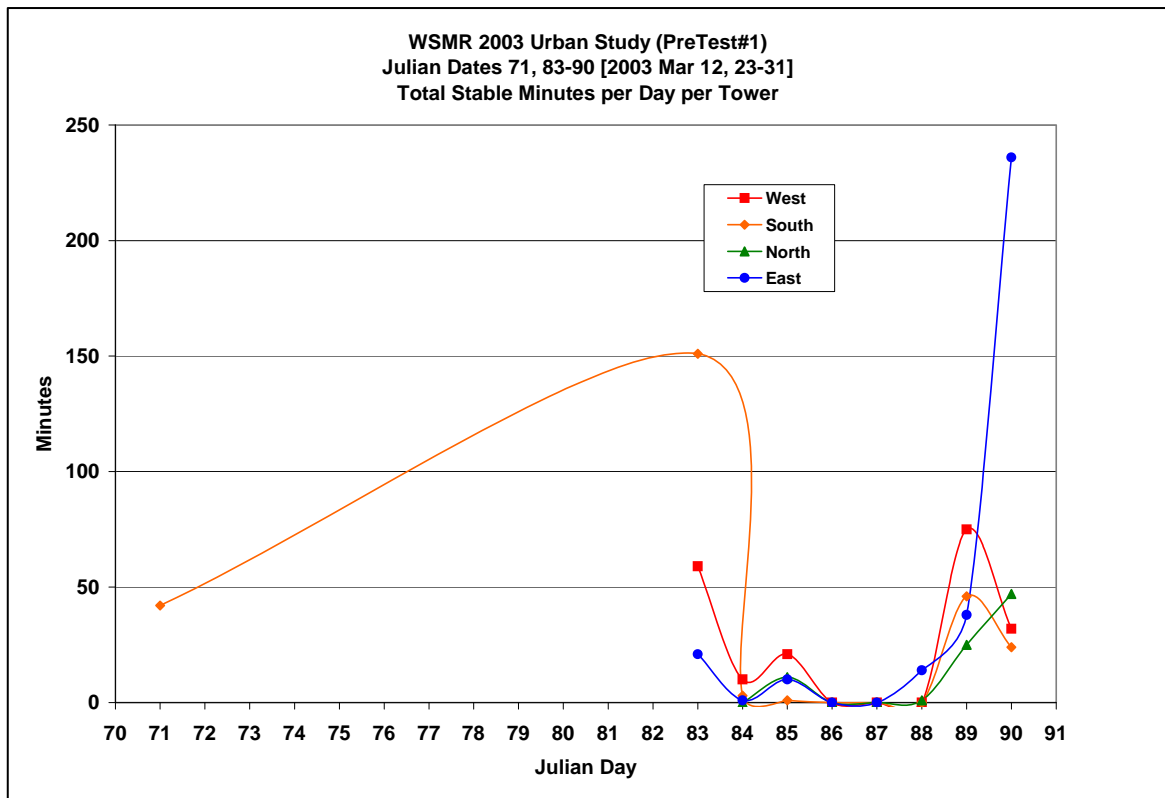
Figure B-3. Total stable minutes per day per tower for the *W03US*.
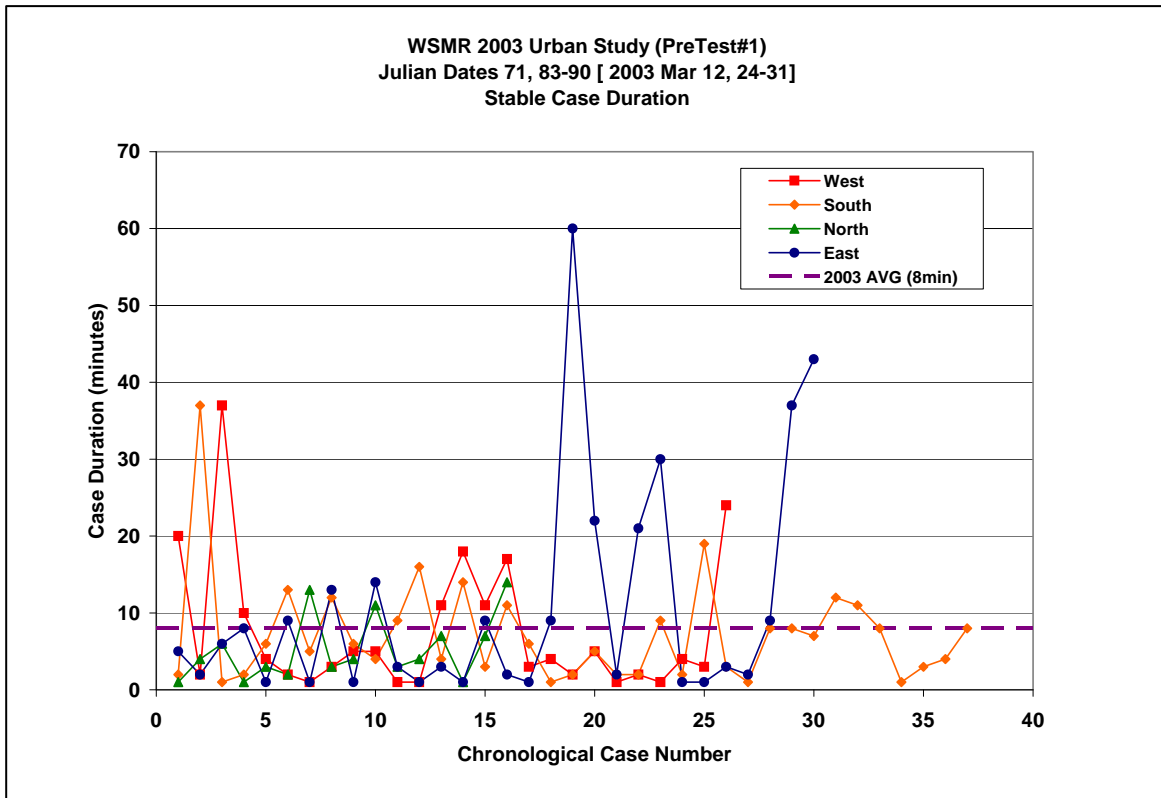
Figure B-4. Stable case duration for the *W03US*.

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Appendix C. *WSMR 2005 Urban Study* – Stable Characterization

Appendix C provides the key *W05US* graphical summaries used in the stable atmospheric characterization inter-comparison (Vaucher, 2007).

WSMR 2005 Urban Study
Percent of Stable Minutes by Tower
[Total Stable Minutes Reported: 1360 minutes]

WEST
11%

SOUTH
14%

EAST
49%

NORTH
26%

Figure C-1. Percent of stable minutes by tower for the *W05US*.

Figure C-2. Minutes in stable condition per day for the *W05US*.

Figure C-3. Total stable minutes per day per tower for the *W05US*.
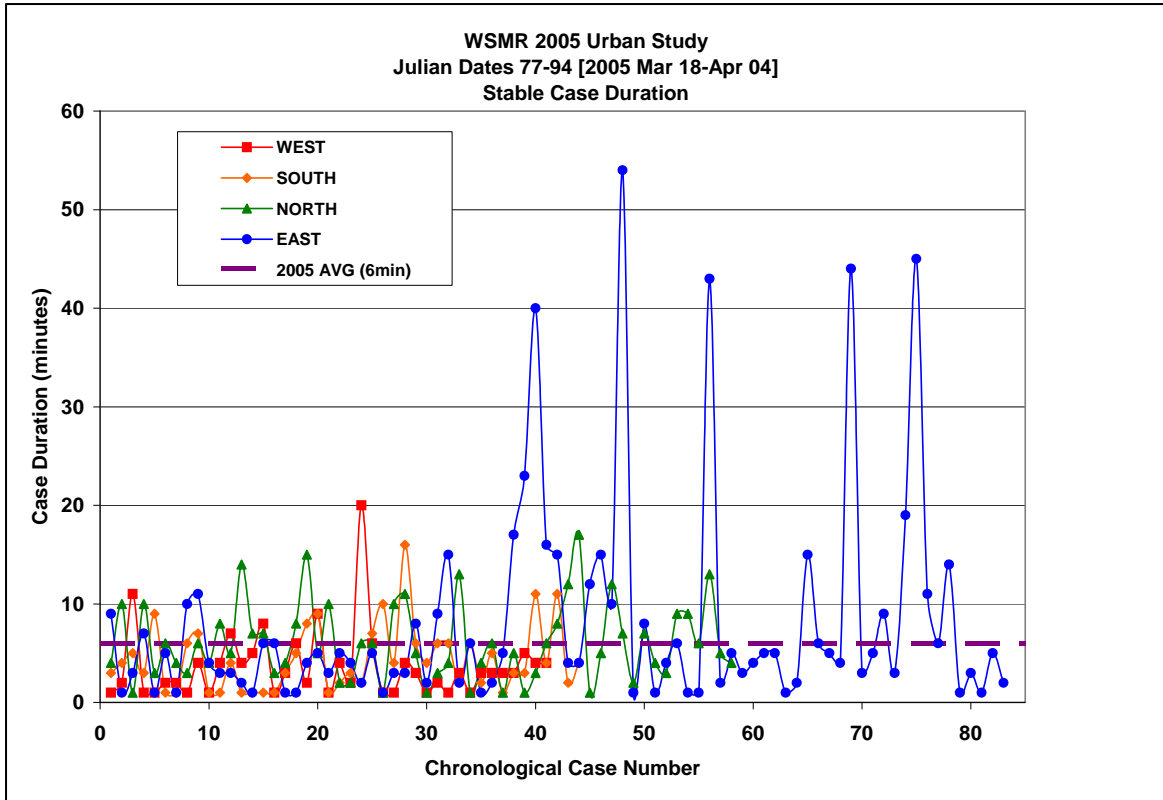
Figure C-4. Stable case duration for the *W05US*.

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Appendix D. *WSMR 2007 Urban Study* – Stable Characterization

Appendix D provides the key *W07US* graphical summaries used in the stable atmospheric characterization inter-comparison.
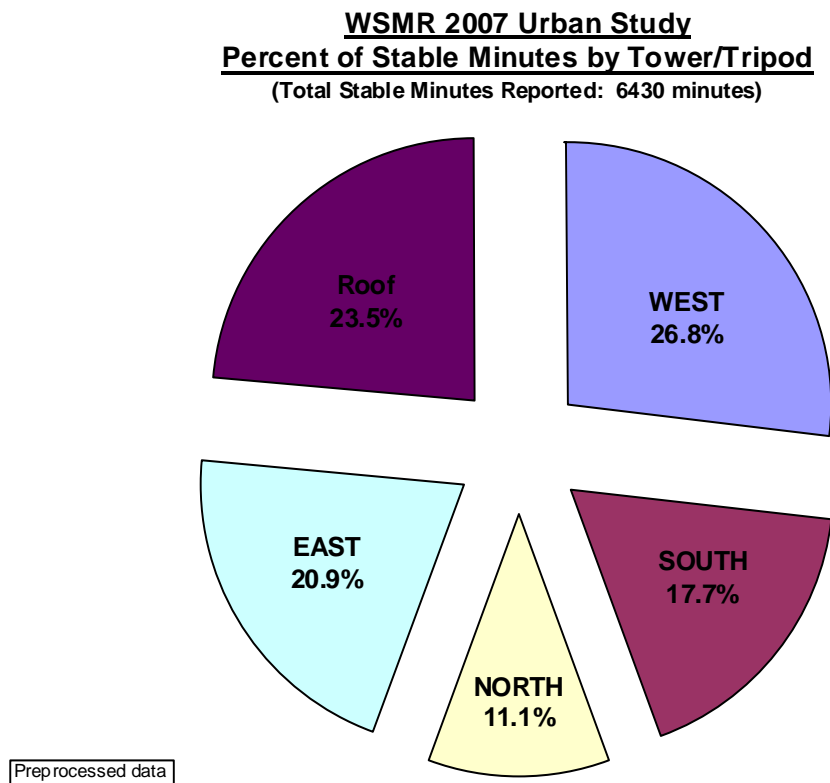
WSMR 2007 Urban Study
Percent of Stable Minutes by Tower/Tripod
(Total Stable Minutes Reported: 6430 minutes)

Figure D-1. Percent of stable minutes by tower for the *W07US*, with Roof data included.

WSMR 2007 Urban Study
Percent of Stable Minutes by Tower/Tripod

[Total Stable Minutes with No Roof Data: 4920 minutes]
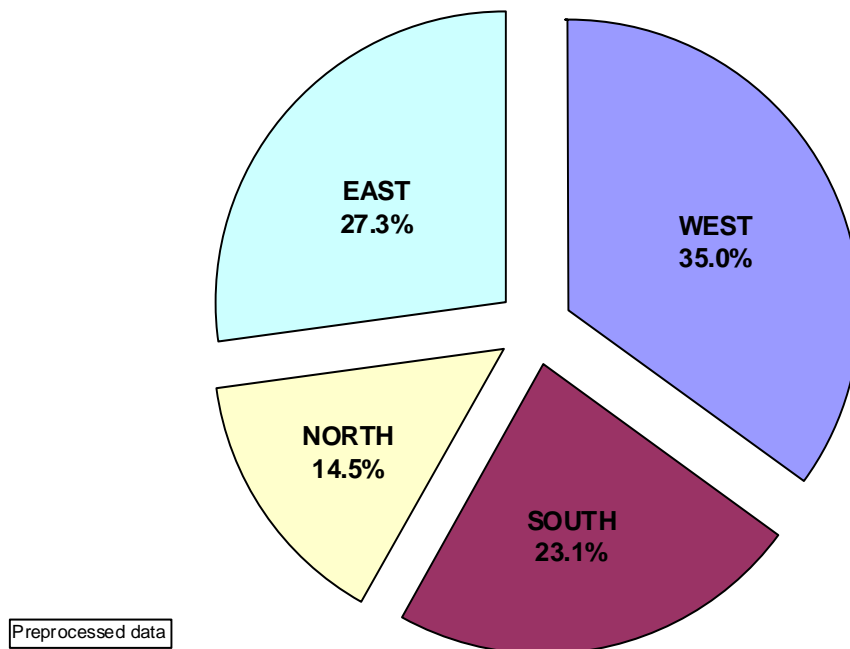

Preprocessed data

Figure D-2. Percent of stable minutes by tower for the *W07US*, with no Roof data included.
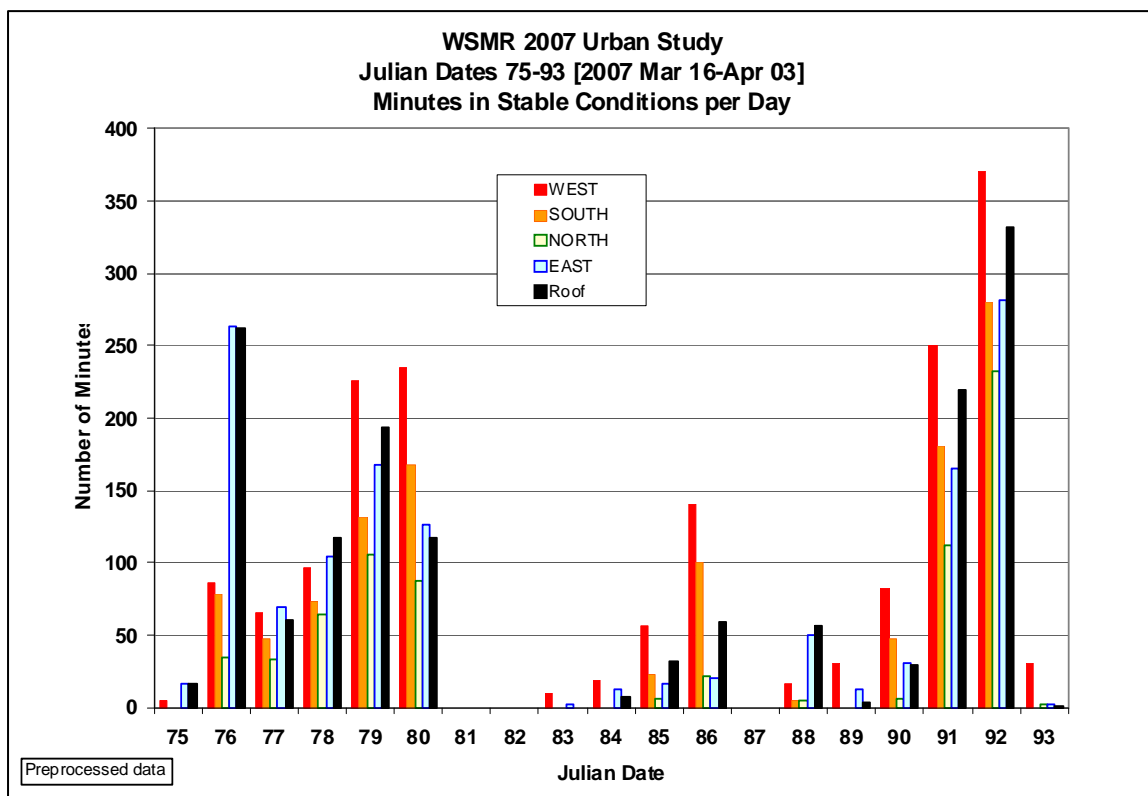

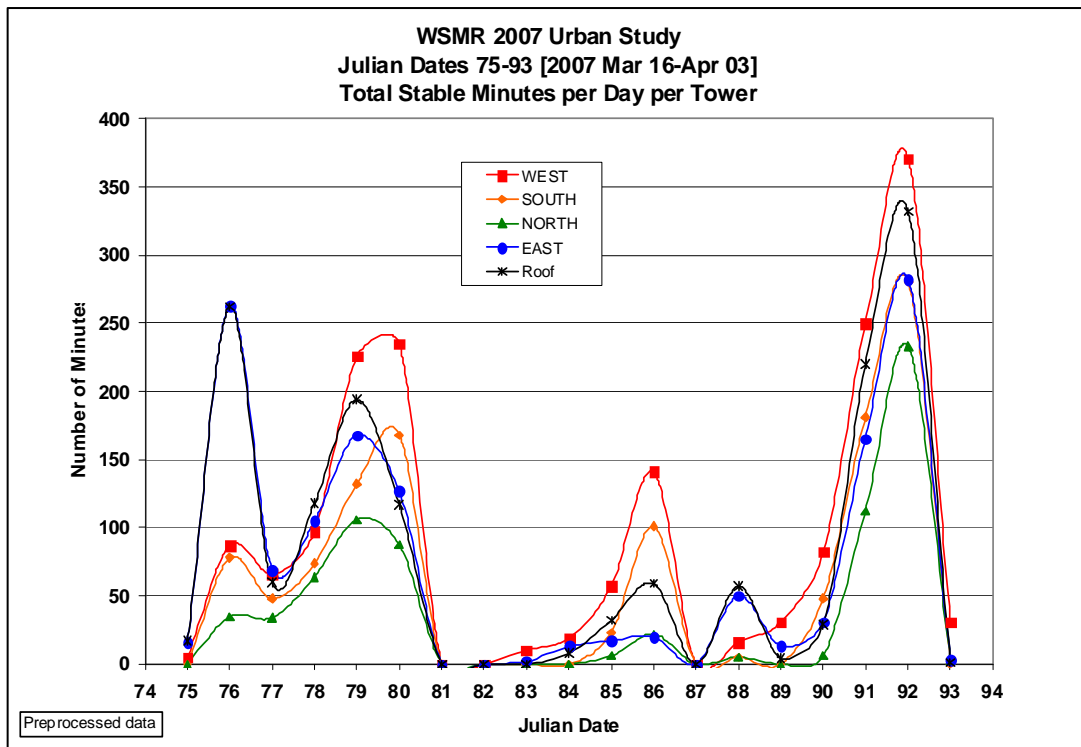Figure D-3. Minutes in stable conditions per day for the *W07US*.

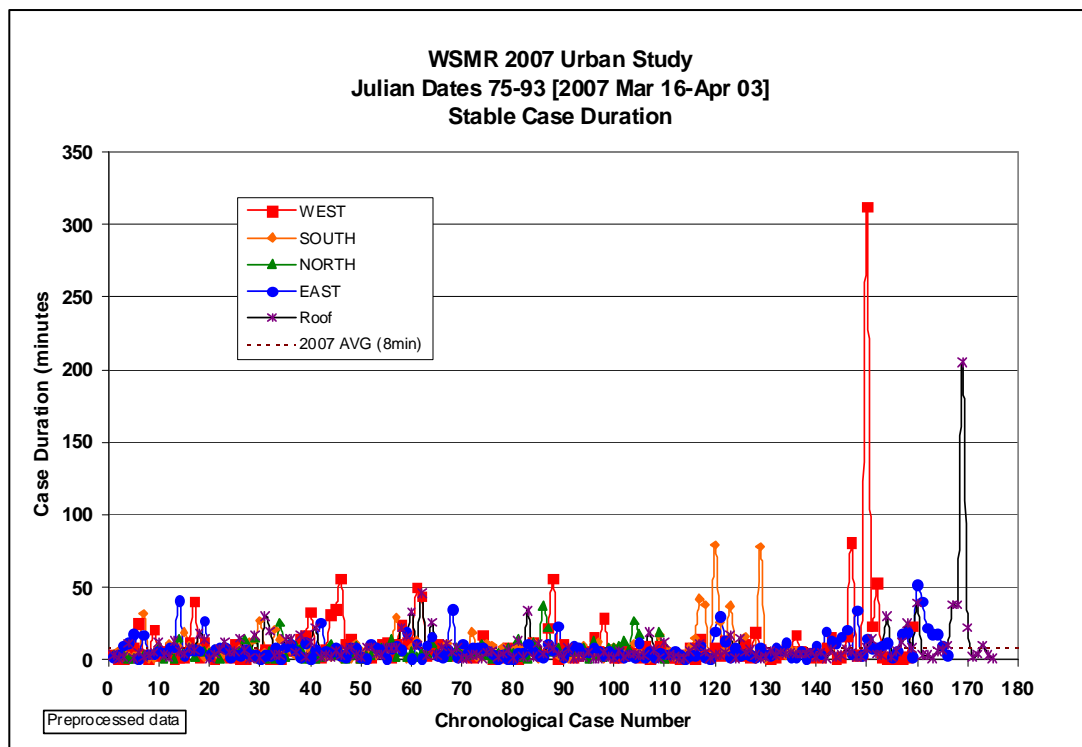Figure D-4. Total stable minutes per day per tower for the *W07US*.

Figure D-5. Stable case duration for the *W07US*.

WSMR 2007 Urban Study - All Towers / Roof Tripod
Temporal Distribution of Stable Minutes

[Total Minutes in Distribution: 6430 minutes]
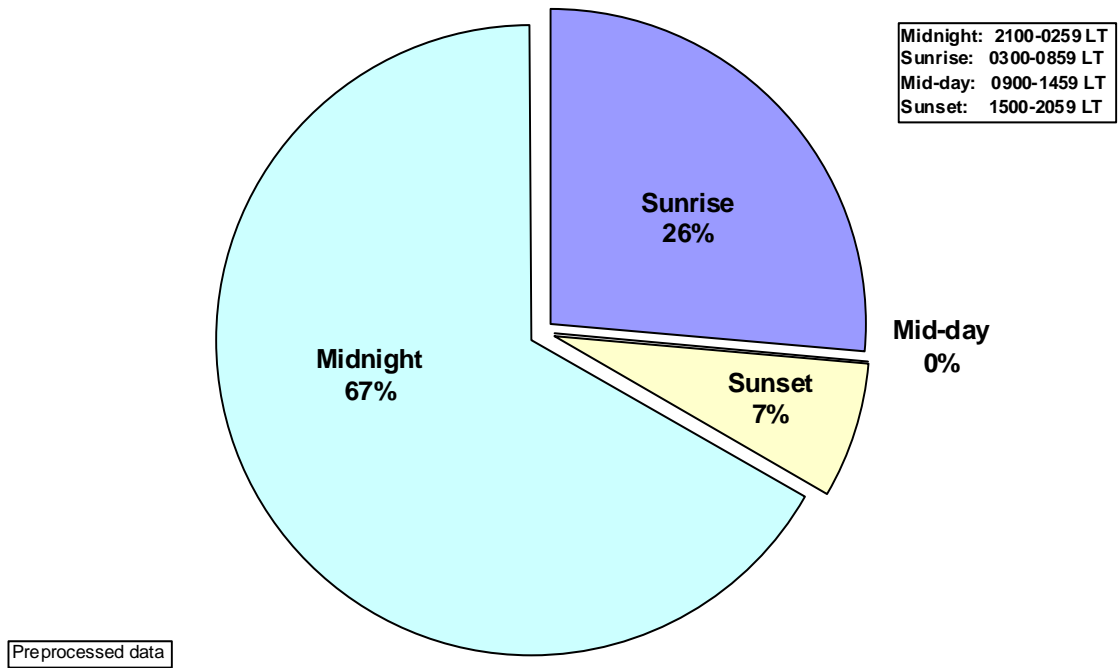
Midnight: 2100-0259 LT
Sunrise: 0300-0859 LT
Mid-day: 0900-1459 LT
Sunset: 1500-2059 LT

Sunrise
26%

Mid-day
0%

Midnight
67%

Sunset
7%

Preprocessed data

Figure D-6. *W07US* quarterly time distribution of stable conditions over a 24-h period.

Acronyms

3DWF	Three-Dimensional Wind Field (model)
AGL	above ground level
DAS	Data Acquisition System
EPA	Environmental Protection Agency
LANL	Los Alamos National Laboratory
LT	local time (mountain time)
NOAA	National Oceanic and Atmospheric Administrations
NWC	northwest canyon
OB/DG	Ocean Breeze-Dry Gulch
QUIC	Quick Urban and Industrial Complex
RE	reattachment-east
W03US	*WSMR 2003 Urban Study*
W05US	*WSMR 2005 Urban Study*
W07US	*WSMR 2007 Urban Study*
WSMR	White Sands Missile Range

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